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# Slow Rate Sand Filtration With and Without Clinoptilolite: A Comparison of Water Quality and Filtration Economics

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# SLOW RATE SAND FILTRATION WITH AND WITHOUT CLINOPTILOLITE: A COMPARISON OF WATER QUALITY AND FILTRATION ECONOMICS

by

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Gordon P. Foreman

# TABLE OF CONTENTS

# LIST OF TABLES

# LIST OF FIGURES

ABSTRACT

Slow Rate Sand Filtration With and Without Clinoptilolite: A Comparison of Water Quality and Filtration Economics

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Slow rate sand filtration (SSF) amended with a 20 cm surface layer of clinoptilolite, a natural zeolite, was compared to SSF with no amendment in a field scale SSF facility treating 85 $m^3/d$ of water. Parameters examined included turbidity, coliforms, and ammonium removal. The control filter with sand and the experimental filter amended with the zeolite were also compared with respect to duration of filter cycle, cold weather operation, and economics.

Amended and unamended filters were approximately equivalent with respect to ammonium and coliform removal at 10° C. The zeolite amended cell was superior to the unamended cell with respect to coliform and turbidity removal at 3° C. The zeolite amended cell had filter cycle durations four times longer and operation and

maintenance costs 25% lower than the unamended cell.

Laboratory column studies were also conducted to compare a control column of construction sand to a homogeneous sand-zeolite mixture, and to SSF amended with zeolite or coarse sand. Construction sand and clinoptilolite were very similar in metal removal efficiency. Head loss developed most rapidly in the SSF column with construction sand only. Head loss developed more slowly resulting in longer filter cycles when the SSF was amended with a zeolite or coarse sand surface layer. A homogeneous sand-clinoptilolite mixture had filter cycles longer than construction sand, but shorter than SSF amended with a coarse surface medium.

Batch reactor tests were utilized to compare adsorption of reovirus to sand and clinoptilolite. Reovirus adsorption was approximately equivalent for the two media.

(114 pages)

# INTRODUCTION

Slow sand filtration (SSF) has been shown to be an economical water treatment alternative for providing water supply needs of small communities worldwide [1]. For treatment rates up to 1250 cubic meters per day, SSF has been found to be less expensive than conventional package treatment plants in the United States [2]. However, SSF technology is not widely used in the United States today, due to a perception of its limitations and a general lack of familiarity with SSF technology and costs among engineers and planners.

The primary advantages of SSF systems include: simplicity of design and operation, lack of need for highly trained operating personnel, resistance to disruption by shock loading, and high quality effluent. Primary disadvantages include the need for relatively large land areas, compared to other systems, high labor costs for scraping, and the requirement of a low turbidity (<20 ntu) influent water. Research which would further demonstrate the effectiveness of SSF technology and would provide designs to achieve lower associated labor costs may provide an impetus for more widespread use of SSF systems in the United States.

Clinoptilolite is a natural ion exchange zeolite which has been primarily of interest due to its high

selectivity for ammonium ions and some heavy metals[3]. It was hypothesized that amending a SSF with clinoptilolite might improve its performance by providing a superior growth medium for the organisms comprising the schmutzdecke.

Data were also obtained on SSF operation through a complete winter season, demonstrating that uncovered SSF operation is feasible in a northern Utah climate.

This research concerning SSF technology, capabilities and limitations is a continuation of research initiated by Slezak[2] and McConnell[4,5]. Slezak[2] conducted a nation-wide survey of operating SSF facilities. He also constructed laboratory columns to compare unsieved construction sands to sands sieved (graded) to meet Utah specifications to determine if the graded sands actually provided superior filter operation. A field scale SSF pilot plant was also designed, constructed, and operated using construction sand to determine if satisfactory flow rates and water quality could be obtained. Finally, Slezak[2] conducted an economic analysis comparing SSF to package treatment plants.

McConnell[4,5] conducted tests with respect to virus and bacteria removal using SSF technologies. Environmental Protection Agency (EPA)[6] standards were consistently met with respect to coliform bacteria when filtering Logan River water. Reovirus concentration was reduced by three

to four orders of magnitude; reovirus also were apparently inactivated.

This research compares SSF amended with a surface layer of zeolite to a SSF with no zeolite amendment. Primary research emphasis was placed on water treatment efficiency and maintenance and operation requirements, with the goal of making water treatment by SSF less labor intensive and more economical.

# REVIEW OF LITERATURE

A water treatment plant serving a small community should be inexpensive both to construct and to operate, yet it must consistently meet federal drinking water standards[6]. One type of plant that meets these criteria is the slow rate sand filter (SSF). SSF facilities are efficient in removing bacteria and suspended solids from water[1], and appear to remove at least some viruses with better than 99.9% efficiency[4,7].

## Heavy Metal Removal from Drinking Water

Metal contaminants, such as Mn, Fe, Pb, Cd, Hg, Zn, Cr, and As, often occur in water supplies, either from natural or industrial sources. Common treatment processes which may affect some of these ions include lime coagualtion with recarbonation, alum coagualtion[8] and lime softening[9]. In particular, lime coagulation may remove up to 90% of the Cu, Fe, Pb, Mn, and Zn present in drinking water, but will remove less than 10% of the Hg or As[8]. Alum coagulation may remove more than 90% of the Pb and Cu present, but will generally reduce Zn by less than 50%[8]. Lime softening may reduce all these metals (except As, which exists as an anion in aqueous systems) through a common ion effect, but this is usually not

practiced in treatment plants of less than 3800 cubic meters per day capacity (1 mgd)[10].

## Ion Exchange Characteristics of Clinoptilolite

One of the primary differences between sand and clinoptilolite is that clinoptilolite is an ion exchange zeolitewith a ction exchnge capacity (CEC) of 60 to 70 meq/100 g, while sand has a very low (CEC) of approximately 5 meq/100 g. Cation exchange refers to the capacity of a solid medium to exchange positively charged ions (cations) located within the medium with other cations in an aqueous solution. Thus

$$R(Na+) + NH_4^+ \rightleftharpoons R(NH_4^+) + Na+ \qquad (1)$$

where R is the cation exchanger[11].

One of the primary criteria used to evaluate an ion exchange medium is its total ion exchange capacity. This is a measure of how many ion exchange sites are available in a given amount of medium, and is usually expressed in terms of milli-equivalents (meq) per 100 grams of medium, where one meq represents one millimole of any single charge ion (H+, Na+, K+, etc.). Thus 0.5 mmole of a double charge ion such as $Ca^{++}$ would represent one meq, as would 0.33 mmole of a triple charge ion such as $Al^{+++}$. The ion exchange capacity of clinoptilolite is 60 to 70

meq/100 g[12]. This was confirmed experimentally by the author.

When a cation exchange medium is in contact with water and two different species of ions are present in both the water and medium, an equilibrium condition will be reached. The selectivity coefficient, $K_A^B$ for this reaction is given by

$$K_A^B = \frac{M_B}{M_A} \times \frac{m_A}{m_B} \qquad (2)$$

where m and M refer to ionic concentrations in solution and medium phase respectively. Thus, depending on the selectivity coefficient, the ratio of ionic species in solution may be quite different from that in the medium[11].

It has been reported that the selectivity coefficient of clinoptilolite is relatively greater for several heavy metals, including Pb, Ag, and Cd, than for common cations identified in water supplies, such as Na, Ca, and Mg[12]. However, this selectivity has not been demonstrated at the sub-milligram per liter concentrations of concern in drinking water. Since national safe drinking water regulations[6] mandate very low levels of these metals, (50 ug/l for Pb and As and 10 ug/l for Cd) removal of these constituents is necessary when drinking water sources exceed these concentrations.

Ammonia Nitrogen in

Drinking Water

Ammonia exists in water as unionized ammonia ($NH_3$) and ammonium ion ($NH_4^+$). The ratio of the two forms is a function of the pH, with the ionic form predominating when the pH is less than 9.3[13]. Unionized ammonia in surface water is limited by the United States Environmental Protection Agency (USEPA) to 20 ug/l[6]. The presence of ammonium may be a result of coke or other chemical manufacture, but is usually the result of agricultural runoff, especially where heavy fertilization has occurred[14].

Small amounts of ammonium, usually one third or less of the chlorine dose by weight, are sometimes added to the in water treatment systems to prevent the formation of chlorophenolic taste and odor[15]. The monochloramine formed has the advantage of persisting in the system much longer than free chlorine (HOCl), but is also at least 25 times less effective at killing bacteria and viruses[15]. Chloramines, primarily nitrogen trichloride, are also associated with much of the objectionable odor associated with chlorination[16]. Thus, the removal of excess ammonium prior to chlorination would reduce chlorine costs and the taste and odor associated with excessive chloramines in conventional water treatment systems.

## Chlorine Demand vs. Turbidity

Turbidity in water is caused by suspended particles, which may be either organic or inorganic in origin. Turbidity resulting from organic matter will exert a chlorine demand and thus increase the quantity of chlorine which must be added to the water to obtain the desired residual[13]. In addition to increasing chlorine usage, some organics combine with chlorine to form objectionable tastes and odors[15]. Finally, turbidity particles may encase pathogens, shielding them from the chlorine, and preventing complete disinfection of the water[13]. For these reasons, the USEPA has established a turbidity limit of 1 nephelometric turbidity unit (ntu) for public drinking water[6]. For a surface water treatment system to be acceptable, it must be capable of reducing turbidity to a level under 1 ntu. SSF technology has demonstrated this capability[1,2,4,5,7].

## Ammonium Ion Exchange Selectivity on Clinoptilolite

Researchers have studied the ion exchange selectivity of clinoptilolite with respect to ammonium, and have found it to be selective for ammonium ions[17,18]. It is possible that this ammonium selectivity may cause clinoptilolite to be superior to sand as a growth medium

for the organisms which comprise the schmutzdecke. Ammonium is a form of nitrogen which is readily available to plants and bacteria for use in cell synthesis[19]. The elemental formula for cellular matter in water and wastewater is sometimes given as $C_{106}N_{45}H_{180}O_{16}P_1$, which indicates the ratios of the elements required for cell growth[20]. Other nutrients are required, but the proportions are far smaller than for C, N, H, O, and P. When the schmutzdecke is mature, therefore, most of the influent ammonium nitrogen should be utilized, since nitrogen is usually the limiting growth consitituent. When the schmutzdecke is not mature, i.e., for a period of one to seven days after scraping, excess ammonium would be exchanged onto the clinoptilolite. This ammonium would then be available to any organisms which could utilize it, including nitrifiers, as it has been demonstrated that ammonium saturated clinoptilolite can be regenerated by nitrifying bacteria[21].

## Nutrient Transfer to the Schmutzdecke Organisms

The nature of nutrient transfer from the water to the organisms of the schmutzdecke has not been examined in great detail. However, it may be similar in many ways to nutrient transfer to the roots of plants. This is thought to take place primarily through three mechanisms[22]. The first mechanism is termed root interception and

refers to the direct transfer of nutrients from the soil colloids to the root. The second mechanism is mass flow, which is the transfer of nutrients through the cell wall as part of the water which passes through the cell wall. The third mechanism is diffusion which occurs as nutrients adjacent to the cell walls are exchanged or absorbed to the interior of the cells but are prevented from returning as they are utilized, creating a lower density of nutrients adjacent to the cell than exists in the solution as a whole[22]. For cations such as $Ca^{++}$ and $K^{+}$, diffusion is considered to be the most important means of supplying nutrients to the plant roots[23]. Another factor cited by Brady[23] as empirically important but not thoroughly understood, is the symbiotic relationship which exists between the plant roots and the microorganisms which dwell in the root zone. It is possible that similar symbiotic relationships may occur between various organisms of the schmutzdecke. The presence of these microorganisms appears to greatly enhance the transfer of nutrients to the plant roots. The uptake of nutrients by algae in lakes and streams is thought to take place by both diffusion and by mass transfer, with diffusion predominating[24].

The primary producer organisms present in a SSF would probably not make use of root interception, although hyphal and trichome interception may be similar. In addition, the primary source of nutrients for the

organisms of the schmutzdecke is the influent water. This is in contrast to terrestrial plants where the soil-root system is the primary source or nutrients. Since the schmutzdecke is continuously saturated by water, the transfer of nutrients may occur by the other two mechanisms discussed, i.e., mass flow and diffusion.

## Virus Removal and Inactivation by SSF

Another important aspect of water treatment and purification is the removal and inactivation of viruses. Removal of viruses by solid media is considered to occur primarily by adsorption[25,26,27,28,29]. It has been shown, however, that virus removal by SSF with a mature schmutzdecke is sometimes 2 to 4 log units greater than virus removal by a clean sand bed at similar flow rates[30,7]. Therefore, adsorption may not be the primary removal mechanism in a SSF, although results obtained by McConnell[5] demonstrated that no detectable reovirus was found in the effluent from 60 cm sand beds, regardless of the presence or absence of a schmutzdecke. This would indicate, at least for the specific conditions of the test, that adsorption was highly effective in removing reovirus. The small size of viruses (20 to 300 nm diameter) precludes removal by straining processes except for solids-associated viruses.

Adsorption occurs through several mechanisms,

including chemical bonding, chemical bridging and electrostatic interactions between particles[25,31]. The extent of adsorption is greatly affected by environmental factors including pH, ionic strength and organic content, and by virus type and flow rate through the system[26].

The variable results obtained with clean sand indicate that the use of clean sand cannot ensure consistent removal of viruses of differing types under differing conditions. Removal of bacteria and viruses in the schmutzdecke is thought to be primarily a function of biological activity, since removal increases in many cases with increasing age of the schmutzdecke[32,33]. Lloyd[34] identified the most prominent species of the microfaunal community in a SSF as belonging to either the phylum Protozoa or the class Rotifera. Bacteria and fungi were also plentiful. This implies that the ultimate removal of pathogens in the schmutzdecke is by consumption rather than adsorption. In this case, virtually all pathogenic bacteria or viruses which cannot reproduce and grow in the schmutzdecke should be inactivated by the other organisms present.

## Winter Treatment Efficiency

A slow sand filter in northern climates must operate in extremes of temperature which can cause serious operation and maintenance and quality control problems. Huisman and Wood[1] reported that the bacteriological

treatment efficiency of a slow sand filter may be unacceptable when the water temperature drops below 7° C. Poynter and Slade[7] reported a 2 log reduction in poliovirus removal when water temperatures decreased from 11° to 6° C. However, further research by Slade[35] indicated that virus removal was relatively independent of low water temperature in that no virus was detected in the effluent at any temperature. These results are contradictory, which indicates that water temperature may affect treatment efficiency greatly in some SSF systems, while treatment efficiency of other systems may be affected very little by fluctuations in temperature. Therefore, treatment efficiency at varying temperatures should be evaluated carefully for every SSF system to determine if water temperature is an important variable for that system. In general it appears that some systems may provide satisfactory treatment at all operating temperatures, while others are unable to completely remove influent organisms at lower temperatures.

## RESEARCH OBJECTIVES

The general objective of this research was to compare unamended SSF to SSF amended with a surface layer of clinoptilolite with respect to overall treatment effectiveness. A comparison of costs and treatment efficiencies of unamended SSF versus SSF amended with clinoptilolite was made to determine which system would provide the greatest treatment efficiency at the lowest cost.

Specific research objectives of this project were divided into seven tasks. The first task was to compare bacteriological and turbidity removals for a SSF amended with clinoptilolite to a control SSF with no amendment in a field scale pilot plant. The second task was to compare filter cycle durations and volumes of water filtered before scraping was required to reestablish normal flow (0.2 m/h) through the filters. The third task was to obtain winter season operation data on the field scale pilot plant facility. The fourth task was to evaluate several configurations of clinoptilolite and sand with respect to head loss and water treatment in SSF laboratory columns. The fifth task was to use batch reactor tests to compare viral removal efficiencies of sand versus clinoptilolite, and also to examine biological regeneration of clinoptilolite. The sixth

task was to collect the data necessary to conduct an economic analysis of unamended SSF versus SSF amended with a surface layer of clinoptilolite. The seventh task was to obtain design and operation and maintenance criteria for future SSF systems.

Task One:

Pilot Plant Performance

Influent and effluent turbidity readings were taken to determine the degree of clarification achieved in the SSF. Bacteriological treatment with respect to coliforms was also evaluated by stressing the pilot plant with a slug dose of sewage, and measuring effluent coliforms.

Task Two:

Pilot Plant Filter Cycles

The flow rate through each filter was established manually, and adjustments were made to maintain that flow rate at a constant level. Duration of the filter cycle until that flow rate could no longer be maintained was noted for each cell. Total volumes of water filtered per filter cycle were calculated.

Task Three:

Winter Operation of SSF

Winter operation data were obtained to determine the feasibility of uncovered filter operation in a northern

climate. Design and maintenance and operation criteria necessary for such operation were also obtained.

Task Four:

Column Media Configurations

Since the field scale SSF pilot plant facility could only be used to evaluate two media configurations at one time, laboratory scale glass columns were utilized to examine several configurations simultaneously. The configurations used were monitored to determine head loss development with time, and to evaluate dissolved metal removal for manganese, arsenic, and lead.

Task Five:

Batch Reactor Tests

Bench scale batch reactors were used to compare the equilibrium adsorption concentrations of reovirus to sand and clinoptilolite. The attempt was then made to elute the viruses from the solids to determine how tightly they were bound, and to what degree they were inactivated. Bench scale reactors were also used in an attempt to evaluate the possibility of biological regeneration of clinoptilolite saturated with ammonium.

Task Six:

Economic Evaluation

Operational data were collected to provide a cost

comparison of unamended SSF to a SSF amended with a surface layer of clinoptilolite. The economic analysis of Slezak[2] was used as the foundation of this comparison.

Task Seven: Pilot Plant

Design and O&M Improvements

Problems with operation and maintenance of the pilot plant were noted. The objective was to suggest design specifications and O&M proceedures which should be incorporated in future SSF facilities. Most of them serve to reduce or eliminate problems encountered with winter operation.

# MATERIALS AND METHODS

## Field Scale SSF Facility

A field scale SSF facility was designed by Slezak[2] and constructed on the north bank of the Logan River approximately 100 meters west of the Utah Water Research Laboratory (UWRL). The facility consists of a preliminary settling tank and two filters, each 3 meters square, with pumps, piping, gages, and valves sufficient to maintain and regulate the flow of water through each of the filters independently (see Figure 1). The east cell of the pilot plant originally contained one meter of unseived construction sand on a gravel filter drain. The unsieved construction sand had a uniformity coefficient of 4.4 and a $D_{10}$ of 0.18 mm. The uniformity coefficient is the ratio of the sieve size which will pass 60% of the sand divided by the sieve size which will pass 10% of the sand. The sieve size which will pass 10% of the sand is referred to as the $D_{10}$. On 29 March 1984 a 15 cm layer of coarse sand (+ 0.6 mm diameter) was placed on the surface of the east cell, replacing sand removed by scraping in the normal course of operation. The west cell contains 80 cm of construction sand of identical provenance to that in the east cell covered by a 20 cm layer of clinoptilolite crushed and sieved such that all particles were between

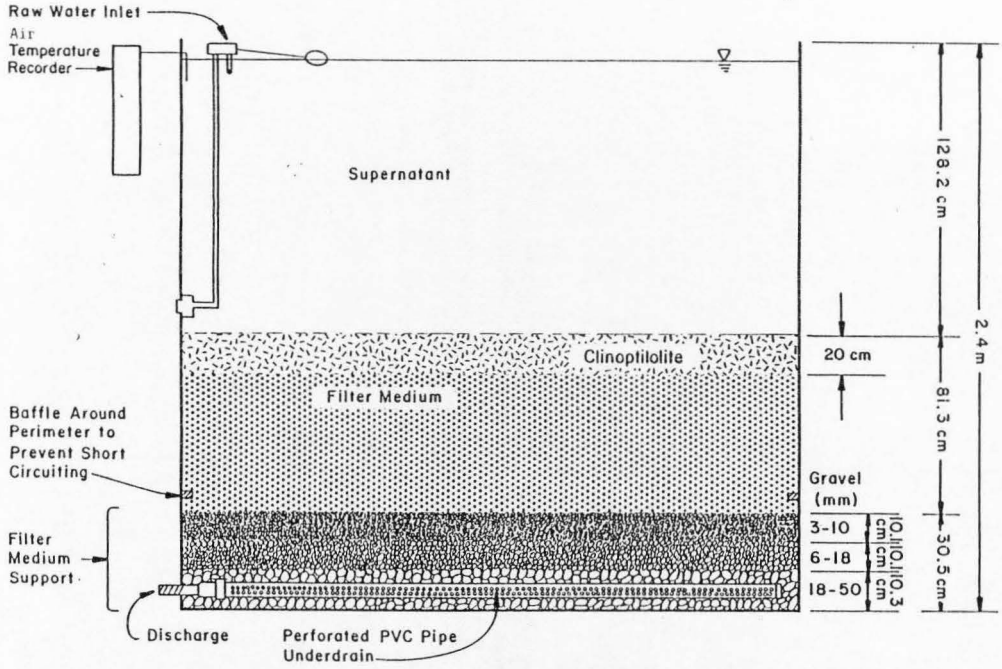


Figure 1. Cross-section of SSF cell in field scale pilot plant facility, showing clinoptilolite layer.

0.7 and 1.7 mm diameter.

When freezing is not a problem, water is pumped from the Logan River into the preliminary settling tank and flows by gravity into the filters, where the water level is controled by float valves. When freezing is a problem, water is pumped directly to the filter tanks, and flow rates are controlled manually. Water flows by gravity through the filters and into a V-notch weir box, where samples can be taken for water quality analysis, before returning to the river.

Temperature Record

Strip chart thermographs were installed at the pilot plant in order to provide a continuous record of air and water temperatures. A Weather-Hawk 7-day remote sensing thermograph was used for continuous monitoring of the effluent water temperatures. Air temperatures were monitored using a spring loaded thermograph mounted in a box under the railing on the side of the filters (see Figure 1). A gap of 30 cm was left between the box and the side of the tank to minimize interference from the temperature of the water in the filter. Recordings were taken on weekly strip charts beginning in Septemper, 1983, and continuing until April, 1984.

Ammonium Reduction in the
Pilot Plant

Ammonium chloride was added to both cells of the field scale SSF pilot plant on 7 June 1984, to determine the removal efficiencies for ammonium in both cells of the plant. A solution containing 220 grams of ammonium chloride in 20 liters of water was added to each cell of the pilot plant, resulting in a supernatant solution containing approximately 5 mg/l of ammonium nitrogen. When ammonium chloride is added to Logan River water, which has a pH of approximately 8.3, about 10% of the ammonium ions will give up a hydrogen ion and revert to unionized ammonia in the aqueous solution. This ammonia can volatize into the atmosphere. For this reason a control solution of 5 mg/l of ammonium nitrogen was also kept at 12° C and sampled initially and at 24 hours for ammonium to determine if volatilization losses were significant. A 24 hour test was done because the detention time for the cell amended with coarse sand was about 24 hours, while the detention time in the other cell was much less. Effluent samples from both cells were taken initially, and at 2, 4, 6, 9, 13, 24, 48, and 72 hours to be analyzed for ammonium nitrogen, nitrate nitrogen, and nitrite nitrogen. An influent sample was also taken before the addition of the ammonium chloride to allow a determination of background levels of

ammonium nitrate and nitrate.

Coliform Removal in
the Pilot Plant

The treatment effectiveness (with respect to coliform bacteria) of the two cells of the field scale pilot plant facility was evaluated on two occasions. In both cases each cell was spiked with 20 liters of raw sewage from the Hyrum Wastewater Treatment Plant, and the effluent levels of coliform bacteria were monitored for several days.

The first test began on 19 March 1984, ten days prior to placing the coarse sand on the east filter, when the water temperature was 3° C, and the supernatant water with sewage contained approximately 2500 coliforms per 100 ml sample. Samples were taken at 0, 2, 6, 10, 24, and 48 hours and also at one week. Sample sizes ranged from 180 ml (3 replicates each at 10 and 50 ml) to 1830 ml (3 replicates each at 10, 100, and 500 ml) at the 24 hr, 48 hr, and one week tests. Results were converted to coliform bacteria per 100 ml by means of equation 3, according to the procedure given in Standard Methods [36].

$$\frac{\text{Total coliforms} \times 100}{\text{Volume filtered in ml}} = \text{Coliforms/100 ml} \qquad (3)$$

Flow rates through the media were 20 cm per hour

for the cell amended with clinoptilolite and 12 cm per hour for the sand cell, which were the maximum flow rates obtainable.

The data obtained were insufficient to derive satisfactory confidence intervals for specific segments of the data plot. However, the binomial probability function[37] was used to determine the overall probability that a coliform bacterium would pass the amended filter versus the unamended filter (Appendix D).

The second test began on 7 June 1984, when the water temperature was 10° C, and the supernatant water with sewage contained approximately 17,000 coliforms per 100 ml. A surface layer of coarse sand was present on the east filter. Samples were taken at 0, 2, 4, 6, 9, 13, 24, and 48 hours, and all samples were 1500 ml in size. Flow rates through the cells were 13 cm per hour for the cell amended with clinoptilolite and 3 cm per hour for the cell amended with coarse sand, which again were the maximum flow rates obtainable.

Analysis for coliform bacteria was performed using the membrane filter technique[36].

## Volatile Solids Accumulation on the Pilot Plant

The field scale pilot plant facility was drained for scraping on 26 March 1984. Before scraping, surface samples of the schmutzdecke and media were obtained from

both the cell amended with clinoptilolite and the sand cell using a metal cylinder 4.5 cm in diameter to collect plug samples. Three types of samples were taken: schmutzdecke with as little underlying medium as possible; the medium immediately under the schmutzdecke, but with no visible schmutzdecke included; and samples of medium and schmutzdecke combined with no division at the interface. All samples were dried at 103° C overnight, and weighed. They were then heated in a muffle furnace at a temperature of 550° C for a period of one hour, cooled in a desiccator, and the ash free dry weight determined. Control samples of both sand and clinoptilolite were treated in an identical fashion to determine if there was any weight loss not attributable to biological matter.

Turbidity Removal Through
the Pilot Plant

Turbidity levels were measured for the supernatant water and the effluent of each cell of the pilot plant. Samples were taken one to three times weekly from 1 October 1983, to 20 January 1984, and again on 2 May 1984, during the spring runoff. All samples were analyzed using a Hach Turbidimeter. The absolute turbidity values obtained may not be accurate, since the turbidity meter was difficult to calibrate, but the relative values for filter influent and sand and

clinoptilolite effluent are accurate.

## Laboratory Scale Glass Columns

Laboratory scale glass columns were set up in the hydraulics laboratory of the UWRL to examine configurations of sand and clinoptilolite, and to evaluate parameters which could not be tested in the pilot plant due to scale or cost. The construction of these columns is illustrated in figure 2. Each column consisted of two 152 cm lengths of 15 cm diameter glass pipe. The influent water in the columns was piped in from the Logan River. Float valves were used to control the water level in the columns. Beginning on 8 February 1984, air was bubbled through the top 80 cm of supernatant to strip the supersaturated fraction of air from the water. Pieziometer ports were installed at 30 cm intervals in the lower section of the glass pipe of each column (Figure 2). Five configurations of media were placed in the columns (Figure 3).

## Metal Removal Studies with Columns

Two laboratory scale glass columns were used to examine the removal of lead (Pb), manganese (Mn), and arsenic (As) from influent water. Column 1 consisted of a 20 cm layer of clinoptilolite on top of 100 cm of unseived construction sand. Column 3 consisted of 105

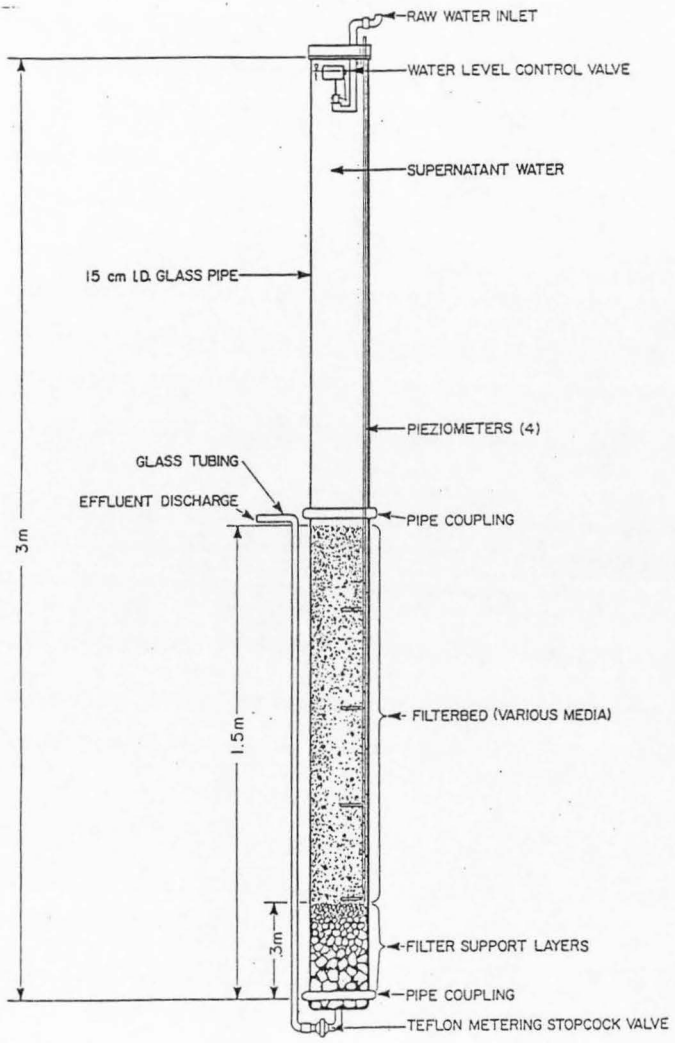


Figure 2. Typical laboratory glass SSF column.

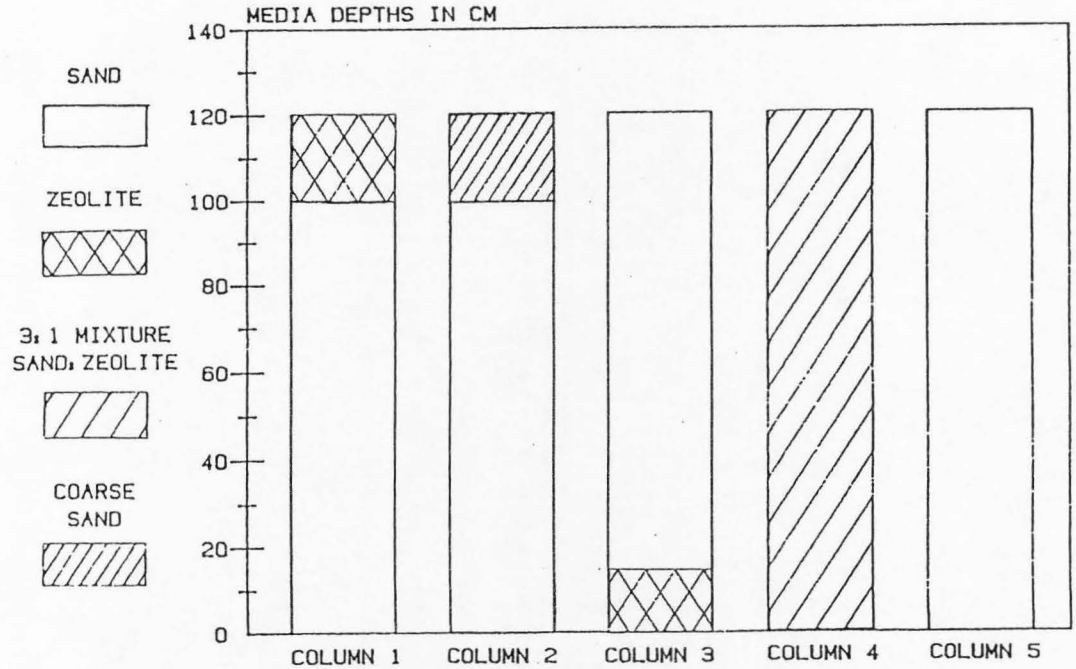


Figure 3. The various media configurations and their depths in the laboratory columns.

cm of unseived construction sand on top of a 15 cm layer of clinoptilolite. Column 5 contained only unseived construction sand, and was used as a control column to which no metals were applied. The water depth over the media was maintained at 140 cm. The flow rate of water through the media was 20 cm depth per hour, or 1 milliliter (ml) per second. A stock solution of Pb, Mn, and As (as lead nitrate, manganese chloride, and sodium arsenate) was prepared, containing 6 mg/l of each, and a peristaltic pump was used to feed this solution into columns 1 and 3 at a rate of 1 ml/minute. This flow rate was designed to produce a concentration of 100 micrograms/liter (µg/l) of each of the metals in the supernatant water. This solution flowed through the columns for a period of 28 days to allow the system to stabilize and to allow measurable quantities of metals to be deposited on the various media. Influent samples were analyzed at 1 day and 14 days to determine actual dissolved metal concentrations in the influent. Effluent water samples were taken twice weekly for metal analysis. Filter flow rates were carefully maintained at 20 cm/hr to establish a steady state condition.

After the four week metal application period, water was drained from the columns and samples of the media were removed from each column at the surface, and at depths of 15, 30, 60, 90, and 120 cm. The samples were dried at 103° C in preparation for acid extraction.

Each sample was then divided into three replicates of 20 grams each, and mixed with 60 ml of 2 molar hydrochloric acid (HCl). All replicates were then agitated continuously for 16 hours on a rotary shaker table. The extract was then filtered through a 0.45 micron glass filter. The replicates of each sample were then combined and analyzed for Pb, Mn, and As, using a Perkin-Elmer Inductively Coupled Plasma Emission Spectrophotometer (ICP). Dissolved As and Pb were below the detection limit using the ICP. Therefore, further analyses were performed for arsenic using the arsine gas generation technique[36]. Total lead concentrations were determined using a Perkin-Elmer Model 5000 Atomic Absorption Spectrophotometer with carbon furnace atomization and Zeeman background correction.

Column Head Loss Study

The columns were placed in service in September, 1983. Bubbles were present in the surface layers of the media, and a sample of the gas comprising the bubbles was collected and analyzed on a gas chromatograph. The source of the bubbles was dissolved air in the influent water, apparently due to the water being brought in from the Logan River under pressure. The temperature of the water also rose several degrees C, depending on the time of the year, which also contributed to the supersaturation of dissolved air.

Columns 2 and 3 were scraped on 1 February 1984, and a compressed air system was set up on 8 February to bubble air through the top 80 cm of supernatant. This was done to eliminate any possibility of greater than saturation concentrations of gases being present in the water. The water was also analyzed for dissolved oxygen using the Winkler technique[36]. On 15 February, a record of head loss development through each column was begun by measuring the head on each pieziometer in each column three times weekly. Columns 1, 3, and 5 were taken out of service on 12 April for metals testing. Column 4 was scraped on 6 June, and columns 2 and 4 remained in operation through 10 August 1984.

Determination of Clinoptilolite
Cation Exchange Capacity (CEC)

A 100 gram sample of clinoptilolite was placed in 500 ml of an aqueous solution of 2 molar NaCl and stirred for 3 hours [38]. The NaCl solution was drained off and replaced with another 500 ml of 2 molar NaCl, and stirred for 15 hours. The solids were separated from the NaCl solution, and the solution was discarded. The solids were washed three times with DDW and placed in 500 ml of 2 molar KCl and stirred for 24 hours. The supernatant was removed and filtered. The filtrate was analyzed for Na on a Varion Techtron Model AA-6 Atomic Absorption Spectrophotometer.

Biological Regeneration of
Clinoptilolite

Each of three 100 gram samples of clinoptilolite was placed in 330 ml of a 1 M solution of ammonium chloride and stirred for 24 hours, beginning on 14 August 1984. This resulted in loading most of the ion exchange sites available on the clinoptilolite with ammonium ions. The clinoptilolite was then washed three times with deionized distilled water (DDW) to remove the excess ammonium chloride solution. Sample 1 was saved for ammonium extraction at the end of the test. Sample 2 was placed in a 1000 ml beaker and covered with 900 ml of filtered Logan River water. Sample 3 was also placed in a 1000 ml beaker and covered with 800 ml of filtered Logan River water and 100 ml of settled activated sludge from the Hyrum Wastewater Treatment Plant to supply nitrifying organisms. Samples 2 and 3 were both stirred at 25 rpm using a jar test stirrer. Supernatant samples were collected initially, and at 1, 2, 4, 7, 10, 24, 48, and 72 hours to be analyzed for nitrate and nitrite nitrogen. Nitrate and nitrite nitrogen analysis was performed using an automated chemistry analyzer (Technicon Autoanalyzer II).

Ammonium nitrogen analysis was performed on the remaining supernatant in samples 2 and 3 after the conclusion of the 72 hour nitrate analysis. The

clinoptilolite in each beaker was washed three times with DDW, and placed in 500 ml of 3 M potassium chloride which should remove at least 96% of the remaining ammonium ions from the clinoptilolite[38]. The same process was performed on the clinoptilolite in sample 1 to determine how much ammonium nitrogen had been exchanged onto the clinoptilolite at the beginning of the experiment. Ammonium samples were analyzed according to Standard Methods[36]. Since levels of potassium chloride of 100 to 1500 mg/l (after dilutions) were also present in the extracted samples, standards were run with and without 1500 mg/l of potassium chloride.

Adsorption of Reovirus to
Sand and Clinoptilolite

The adsorption of reovirus type 1 to clinoptilolite and sand was compared in a 42 hour jar test. Ten grams of washed solid media and 20 ml of Logan River water, filtered through a slow rate sand filter, were placed in a 125 ml erlenmeyer flask and swirled for 42 hours at room temperature (18±2° C). Each flask contained 240,000 counts/minute Iodine-125 labeled reovirus and one of four concentrations of infectious reovirus. Each combination of media and virus concentration was tested in triplicate.

At the conclusion of 42 hours of shaking, a

considerable amount of fines had been generated in both types of media. The fines in the clinoptilolite flasks were extremely fine, and remained in suspension even after standing quiescent for two days. The fines were separated from the clear supernatent by centrifugation for one hour at 2,500 x g. The concentrations of reovirus in the three fractions (coarse solid media, fines, and clear water) were then determined by assaying for the iodine-125 labeled reovirus in each fraction.

The reovirus were iodinated by the chloramine-T procedure[39]. Although the level of infectious virus in the iodinated reovirus tracer was very low, the concentration of reovirus particles in the tracer was 1x10E7/ml after dilution in the Logan River water. The concentration was determined by measuring the optical density of an extremely concentrated (on the order of 10E13 particles per ml) solution of reovirus, and then making known dilutions of the original titer[40].

A buffer (1M glycine; 0.01 M glutamic acid; 0.01 M aspartic acid; and 0.05% tween 20, pH 3.0) which elutes reovirus from charge modified cellulose filters with an elution efficiency of 85% was used to elute reovirus from the sand and clinoptilolite. This buffer elution procedure (developed at Utah State University) is a modification of the technique used by Smith and Gerba[41] for elution of rotavirus from charge modified cellulose filters.

# RESULTS AND DISCUSSION

## Temperature Profile at the Pilot Plant

The water temperature at the pilot plant was 10° C on 1 October 1983, and decreased with minor fluctuations to 3° C on 1 December. Diurnal variations were generally on the order of ±1° C. The temperature fluctuated between 1.5 and 3.5° C until 1 April 1984, when it began to rise. By 1 May it was approximately 8° C, and remained at about that level throughout the remainder of the spring runoff (Figure 4).

The weekly average high and low air temperatures are shown in Figure 5. The lowest air temperature measured during the winter was -29° C, on 17 January. From about 1 December to 1 March there was a layer of ice on the surface of the supernatant in the filters, but the filters continued in operation.

## Ammonium Reduction in the Pilot Plant

After spiking the pilot plant with ammonium chloride on 7 June 1984, the effluent from both cells were monitored to determine the level of ammonium nitrogen. No effluent sample from either cell of the SSF pilot plant contained levels of ammonium nitrogen above 10

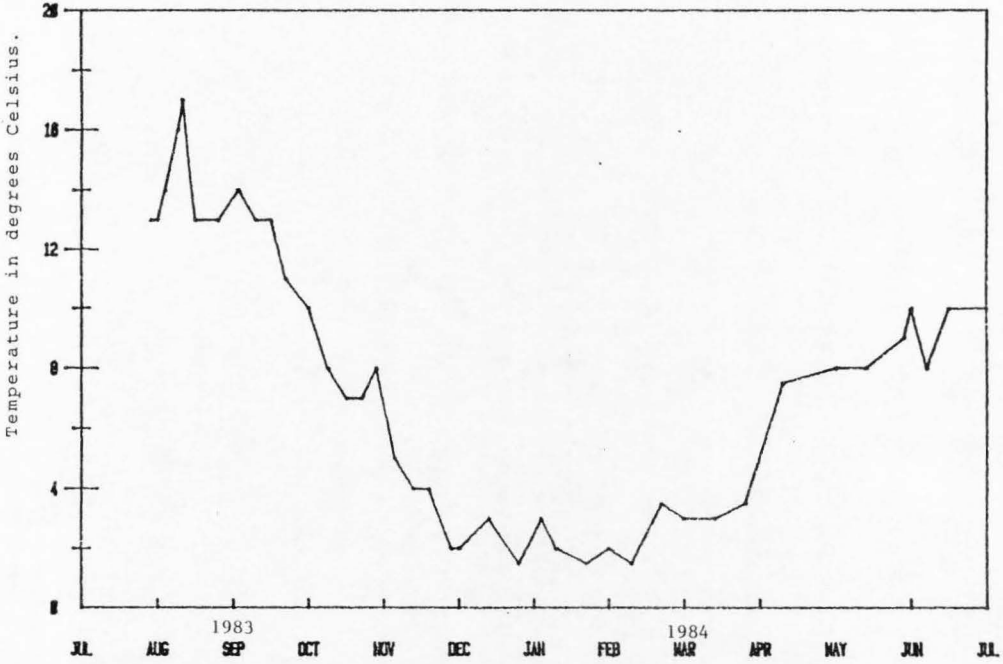


Figure 4. Effluent water temperatures in the pilot plant.

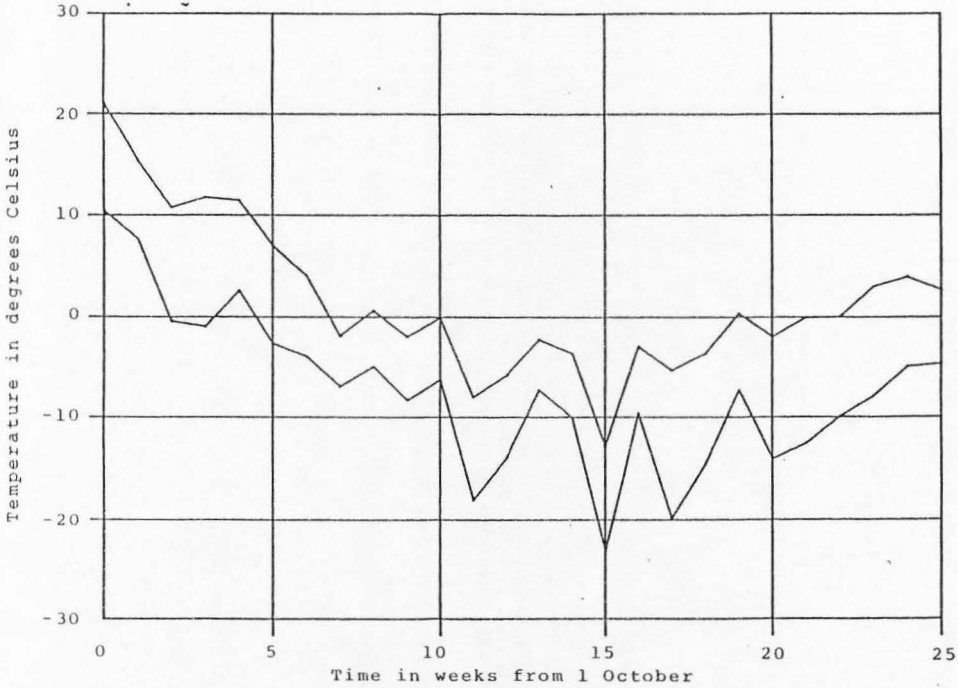


Figure 5. Weekly average high and low air temperatures.

µg/l, which is the detection limit for the low level indophenol ammonia test[36]. Immediately before spiking an influent sample was taken where the background level of ammonium nitrogen in the unfiltered influent water was determined to be 100 µg/l. The ammonium nitrogen level in unfiltered Logan River water was given as 11 µg/l by McConnell[5] (Table 1). The order of magnitude difference observed here is probably due to the fact that samples taken in this study were taken during spring runoff when solids associated ammonium would be much higher. In either case, nitrogen would be the growth limiting constituent, according to Liebig's Law of the Minimum[42], since the weight ratio of nitrogen to phosphorus in cellular matter is approximately 20:1.

In addition to monitoring the pilot plant effluent for ammonium nitrogen, it was also monitored for nitrate and nitrite nitrogen, since it was possible that there were nitrifying bacteria present in the schmutzdecke. Nitrate analysis results (Figure 6) show that the nitrate nitrogen concentration leaving the cell amended with clinoptilolite after the first 24 hours was essentially constant at 0.5 mg/l. Samples were collected several times in the first 24 hours, but they were accidentally discarded by the lab technician before being analyzed. Thus it is not possible to determine changes in nitrate concentration during the first 24 hours. The concentration of nitrate nitrogen leaving the sand cell

Table 1. Raw water quality of the Logan River in October, 1982[4].

| Parameter | Average Value |
|---|---|
| Turbidity | 1.0 ntu |
| pH | 8.3 |
| Electrical Conductivity* | 280 µmhos/cm |
| Alkalinity | 184 mg/l CaCO3 |
| Total Dissolved Solids | 170 mg/l |
| Calcium | 48 mg/l |
| Sodium | <4 mg/l |
| Ammonia-N | 11 ug/l |
| Orthophosphate | 36 ug/l |
| Sulfate-S | 5 mg/l |
| Temperature Range** | 19 - 22° C |

* Corrected to 25° C.

**Temperature of SSF column supernatant measured at the sand bed surface.

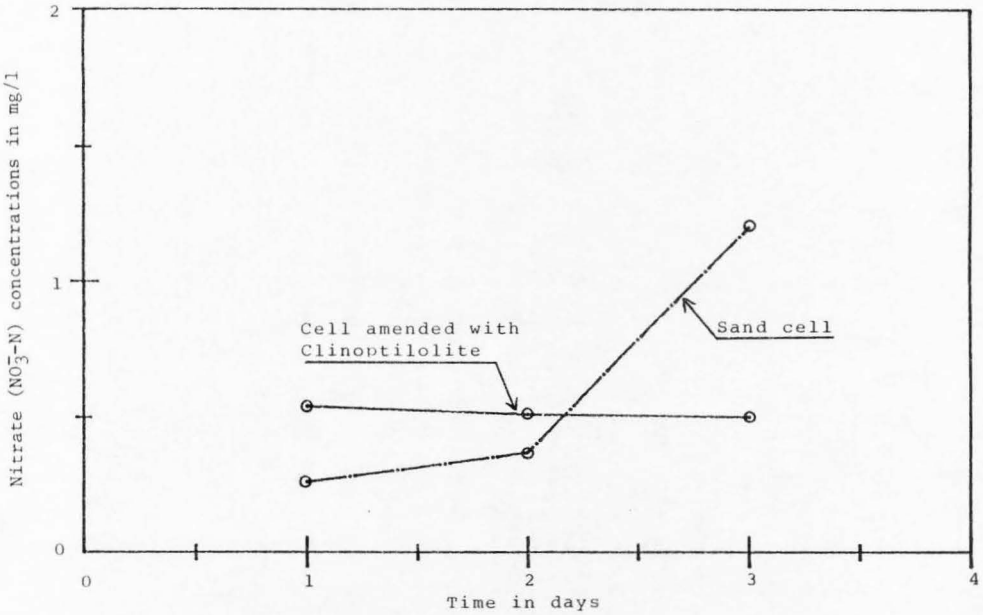


Figure 6. Nitrate ($NO_3^-$-N) concentrations in the effluent from the pilot plant after adding 5 mg/l of $NH_4^+$-N to each cell at T=0.

24 hours after spiking was 0.26 mg/l, and after 72 hours rose to 1.2 mg/l. At this time the flow rates through the cells were approximately 13 cm/hr for the cell amended with clinoptilolite, and 3 cm/hr for the sand cell. The water temperature was 10° C. Integrating flow rate and concentration over time to obtain the total mass of nitrate nitrogen in the effluents indicates that the nitrate nitrogen in the effluent of the cell amended with clinoptilolite accounts for approximately 60% of the influent ammonium nitrogen. That in the sand cell effluent accounts for only about 16% of the influent ammonium nitrogen. Noting the direction and magnitude of the cumulative effluent nitrate curve from both cells (Figure 7), it appears that data should have been taken for several more days to clearly define the results. This was not done because the lab results were not received for several days, and in the meanwhile, the filters had been scraped.

The increase in nitrate nitrogen measured in the effluent from the sand cell indicates that the ammonium nitrogen was retained for 48 to 72 hours before passing through the filter as nitrate. The increase in nitrate concentration may have been due to the time required for the nitrifier population to increase.

The supernatant volume in each cell of the pilot plant models very closely a completely mixed reactor, which means that the concentration of a conservative

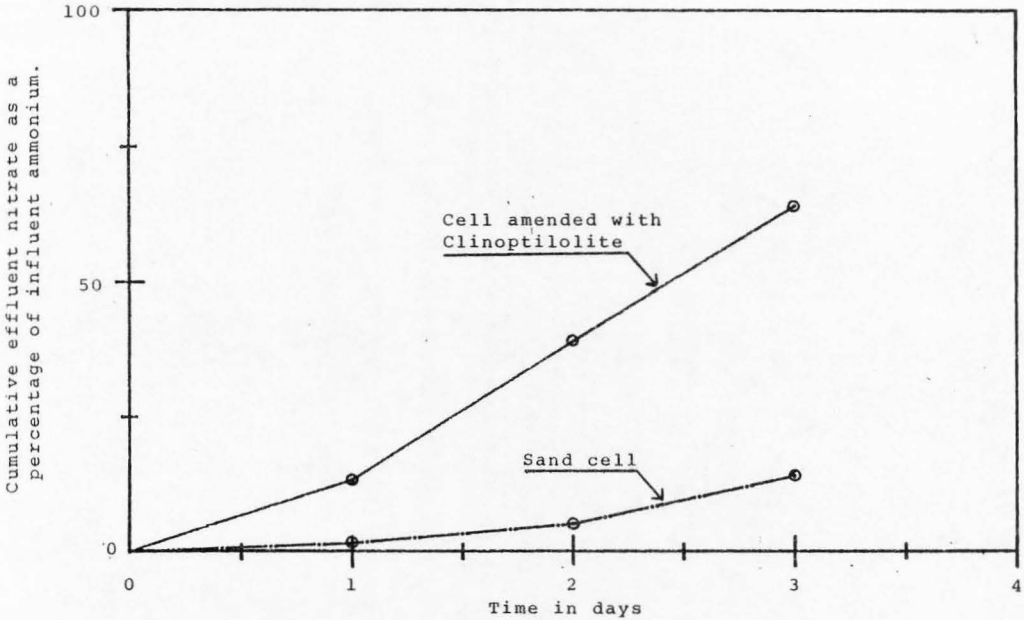


Figure 7. Fraction of influent ammonium detected as effluent nitrate from each cell of the pilot plant.

substance in the supernatant will decrease exponentially. The hydraulics of a completely mixed reactor[43] cause that the concentration of a conservative substrate at any time t after the initial concentration is measured will be given by

$$C = C_0 e^{-\frac{t}{t_0}} \quad (4)$$

where $t_0$ = detention time. The detention time of the cell amended with coarse sand was approximately 1 day. Therefore, the concentration of a conservative substance would have been approximately 5% of the initial concentration after 3 days. The detention time of the cell amended with clinoptilolite was approximately 7 hours, which gives a 3 day concentration of $3.4 \times 10^{-5}$ of the initial concentration.

Neither ammonium nor nitrate nitrogen concentrations in the effluent from either cell decreased at an exponential rate, which indicates that both were affected by processes in the SSF. No ammonium nitrogen was detected in the effluent, which indicates that it was being retained or converted to another form of nitrogen in the filter. The effluent nitrate nitrogen samples taken initially, which would have shown the background concentration of nitrate, were lost. Therefore, it can only be concluded that effluent nitrate concentrations from the cell amended with clinoptilolite were constant from 24 through 72 hours after the addition of ammonium. If the effluent nitrate is a product of the influent

ammonium, then the nitrate nitrogen measured represents 60 to 70% of the ammonium nitrogen added initially. Collection of data over a longer time period would facilitate analysis of the processes occurring in the filter, as would access to the samples from the first 24 hours which were discarded before analysis.

One possibility which can be projected from this analysis is that the risk of exceeding the legal limit of 10 mg/l[6] of nitrate nitrogen in the water exists when SSF systems are used for water treatment. This may be the case even when ammonium nitrogen levels do not reach 10 mg/l. If the background ammonium nitrogen level is usually less than 1 mg/l, then a sudden increase in ammonium concentration, perhaps resulting from agricultural storm runoff, could be stored in the schmutzdecke until the nitrifiers increase to a level where all ammonium nitrogen is utilized or converted to nitrate nitrogen. As the concentration of nitrifiers peaks, this could result in a concentration of nitrate nitrogen in the effluent much higher than the influent concentration of ammonium nitrogen. This possibility is of great concern, because nitrate nitrogen in excess of 10 mg/l may cause methemoglobinemia in infants under the age of 3 months, and is fatal to 7 to 8% of all affected infants[6].

Coliform Removal
in the Pilot Plant

The concentrations of coliforms detected in the filter effluents of the March test are shown in Figure 8. It was shown that the cell amended with clinoptilolite was 95% sure to be at least 3.4 times more effective at removing coliform bacteria than the sand cell (Appendix D). The cell amended with clinoptilolite never exceeded the drinking water standard of one coliform per 100 ml sample, maximum, while the sand cell exceeded that level from the 6 hour test through the 24 hour test. It should be noted here that both cells achieved extensive treatment. Since the influent concentration was approximately 2400 coliforms per 100 ml, the sand cell removed 99.8% of the influent coliforms (calculated at the highest measured effluent concentration), while the cell amended with clinoptilolite removed 99.96%, on the same basis.

In the coliform removal test conducted in June, two coliforms were detected in the effluent of the cell amended with clinoptilolite, while three were detected in the effluent of the cell amended with coarse sand. This was out of a total sample volume for each side of 12 liters, collected over a period of 48 hours, which equates to approximately .02 coliforms per 100 ml. Insufficient numbers of coliforms were detected to determine if a significant difference existed between the

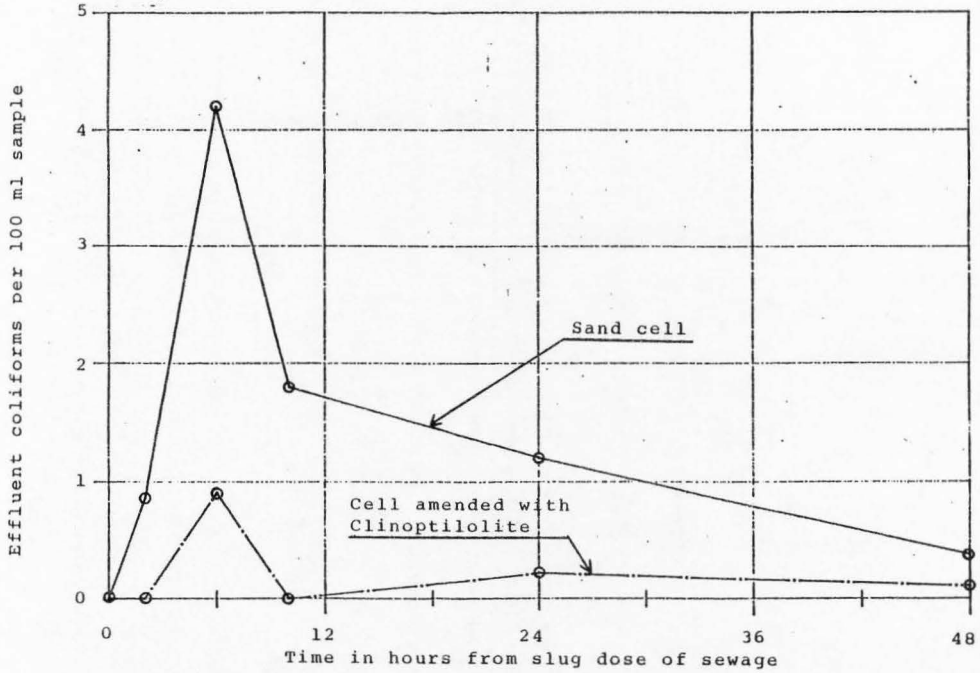


Figure 8. Effluent coliforms per 100 ml sample from each cell of the pilot plant (spiked influent concentration of 2400/100 ml).

cells. Given that the influent coliform concentration for the June trial was approximately 17,000 per 100 ml, the removal rate for both cells was in excess of 99.999%, i.e., 0.02/17,000 = 0.0000012 effluent coliform bacteria per influent bacterium. The flow rate through the cell amended with coarse sand was less than one fourth the flow rate through the cell amended with clinoptilolite. If the flow rates had been equal, the results might have been different.

According to Huisman and Wood[1], the bacteriological treatment efficiency of SSF facilities decreases markedly when the water temperature drops below 7° C. This is supported by the results obtained in these studies. There were four factors which varied between the test in March and the one in June which could be expected to affect the degree of coliform removal: schmutzdecke maturity, flow rates, temperature, and influent coliform concentration. Two of these factors, a less mature schmutzdecke and a higher influent coliform concentration would have tended to result in poorer treatment in the June trial. Since this was not the case, these effects did not predominate. The other two factors, increased temperature and decreased flow rate probably both contributed to the increased treatment obtained in June, but it is not possible, based on the data obtained, to determine which effect predominated.

Volatile Solids on
the Pilot Plant

The measurement of volatile solids is commonly used as a means of determining the fraction of organic matter in a sample . Surface samples from both cells of the pilot plant were collected for volatile solids analysis to compare the fraction of organic matter found on the schmutzdecke of each cell. The volatile solids content of 4.5 cm diameter sample cores differed markedly between the surface of the sand and the surface of the clinoptilolite (figures 9 and 10). A larger fraction of volatile solids was noted on the surface of the clinoptilolite than on the surface of the sand.

Control samples of clean sand and clinoptilolite were also ashed to determine if there was any weight loss not due to biological mass. The sand did not decrease in weight, but the clinoptilolite decreased by 11%, which appeared to be due to waters of hydration being driven off. The presence of waters of hydration of 10.1 to 12.2% of the weight of the clinoptilolite was confirmed by Dr. Matthew Hulbert of International Minerals & Chemical Corporation[44] . All of the samples from the clinoptilolite surface had some clinoptilolite embedded in them, and it was not possible to determine precisely how much. Therefore, volatile solids were estimated from the samples which consisted of primarily schmutzdecke, since they would show the least interference from the

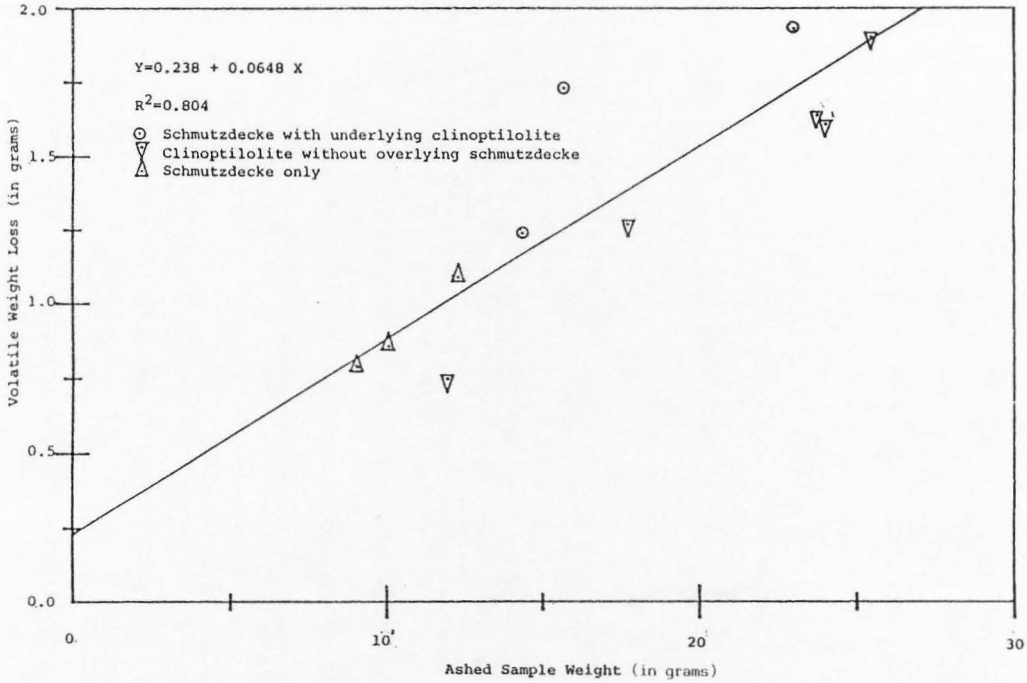


Figure 9. Volatile solids of the schmutzdecke as a function of the total sample weight on the pilot plant cell amended with clinoptilolite.

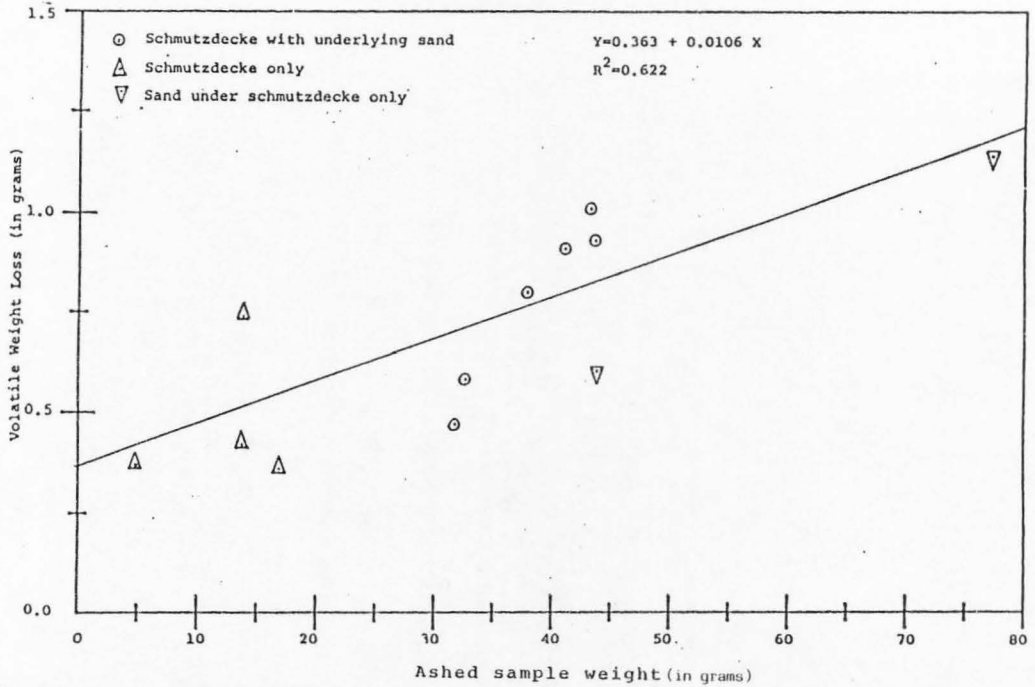


Figure 10. Volatile solids of the schmutzdecke as a function of the total sample weight on the pilot plant cell with unamended sand.

waters of hydration on the clinoptilolite. The resultant weight loss was approximately 0.7 gram per sample, where each sample weighed approximately 10 grams. The sand surface samples which were primarily composed of schmutzdecke showed a weight loss of approximately 0.36 gram per core. When the sand under the schmutzdecke was included, however, the weight loss increased, apparently due to biological matter which was not visible. Thus it appears that the volatile solids in the schmutzdecke were approximately twice as great on the clinoptilolite as on the sand.

The weight loss due to waters of hydration on the clinoptilolite seriously interfered with the measurement of volatile solids beneath the schmutzdecke of the cell amended with clinoptilolite. Although an approximate determination of the volatile solids above the clinoptilolite was made, any determination of volatile solids beneath the surface was not possible. Weight loss for all samples from the clinoptilolite averaged about 8.75%, with little regard for how much clinoptilolite was included in the sample, which indicates that the proportions of volatile matter due to waters of hydration and to biomass are quite similar for these samples. This similarity is supported by the $r^2$ value of 0.804 obtained when linear regression is carried out on the data in Figure 9. The difference between this and the 11% reduction in the clinoptilolite blanks is apparently due

to a fraction of gravel which the supplier inadvertently mixed into the clinoptilolite on the filter. This reduced the proportion by weight of clinoptilolite in the samples. Weight loss for surface samples of the schmutzdecke on the sand appeared to average about 3%, although the variation was much greater than for the clinoptilolite, which is indicated by the $r^2$ value of 0.622. The schmutzdecke on the clinoptilolite was much more homogeneous in appearance than that on the sand when the filters were scraped on 29 March 1984. Therefore, the variability of volatile solids on the surface of the sand may be a function of heterogeneous schmutzdecke development there.

The sand immediately under the schmutzdecke appeared to decrease in weight by about 1.5% when ashed, which indicates that organisms exist at a greater depth in the SSF than the appearance of the schmutzdecke would suggest.

## Turbidity Removal through the Pilot Plant

For the first three weeks after the addition of the clinoptilolite to the surface of the pilot plant, a large fraction of fines washed through, which resulted in much higher turbidities in the effluent than in the influent (44 versus 3 ntu immediately after startup on 1 October, 1985). Within three weeks the turbidity in the effluent

from the cell amended with clinoptilolite decreased to a stable level approximately 30% lower than the turbidity in the effluent from the sand cell, and it remained lower (for all but one reading) after that time (figure 11). This was observed when flow rates through the filters were about equal, and also when the flow rates through the filter amended with clinoptilolite greatly exceeded those through the sand filter. Since influent turbidity is a critical factor influencing the length of filter cycles , it is important that the filter amended with clinoptilolite also had much longer cycles and filtered much more water between scrapings (Figure 12). The slower head loss development in the cell amended with clinoptilolite was observed from 1 April to 10 June 1984, when the sand cell was amended with a layer of coarse sand on its surface (Figure 13). This indicates that slower head loss development is not due entirely to the coarseness of the surface material.

It should be noted that the flow rate through the cell amended with clinoptilolite did not increase as a result of being scraped at the end of March. This indicates that the head loss which had been observed to develop since about 1 February 1984, was not due to the schmutzdecke on the surface of the clinoptilolite. It was reported by Reid[45] that the presence of granular activated carbon (GAC) on the surface of a SSF greatly extended the duration of filter cycles. However,

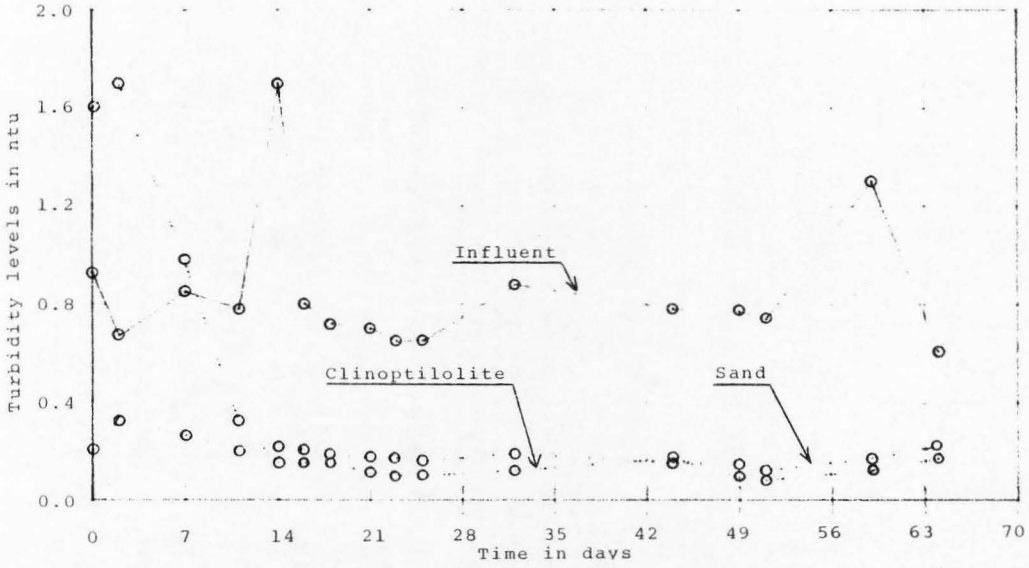


Figure 11. Turbidity levels vs. time in days for the influent to the pilot plant and the effluent from each cell. The clinoptilolite was added on 1 October 1983, T=0 was on 17 October 1983.

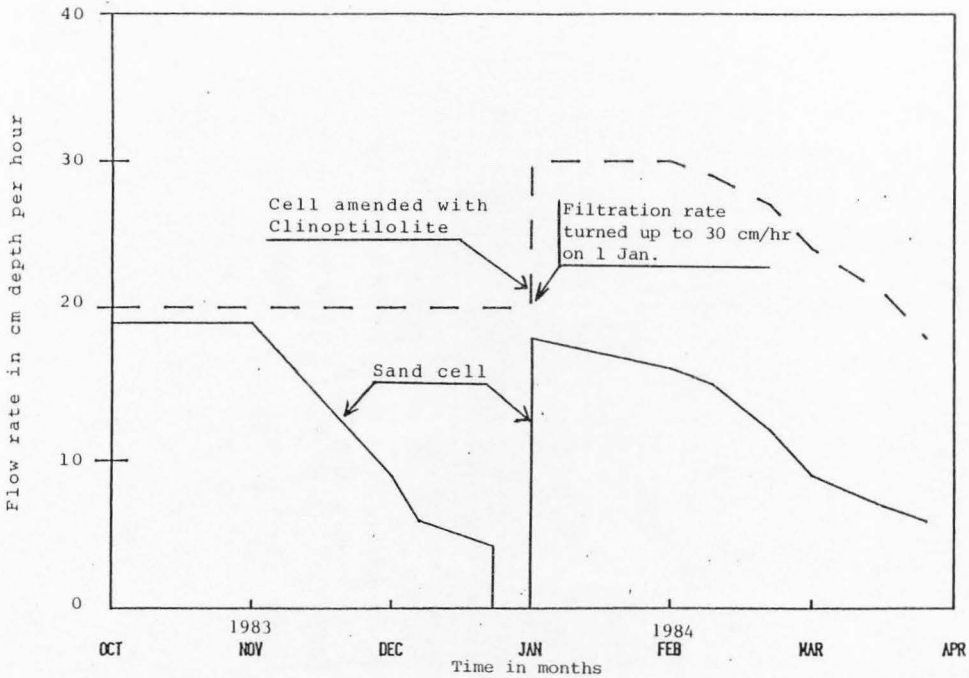


Figure 12. Filtration rates versus time for both cells of the pilot plant during winter operation. Integrated area under the curves indicates total filtered volumes.

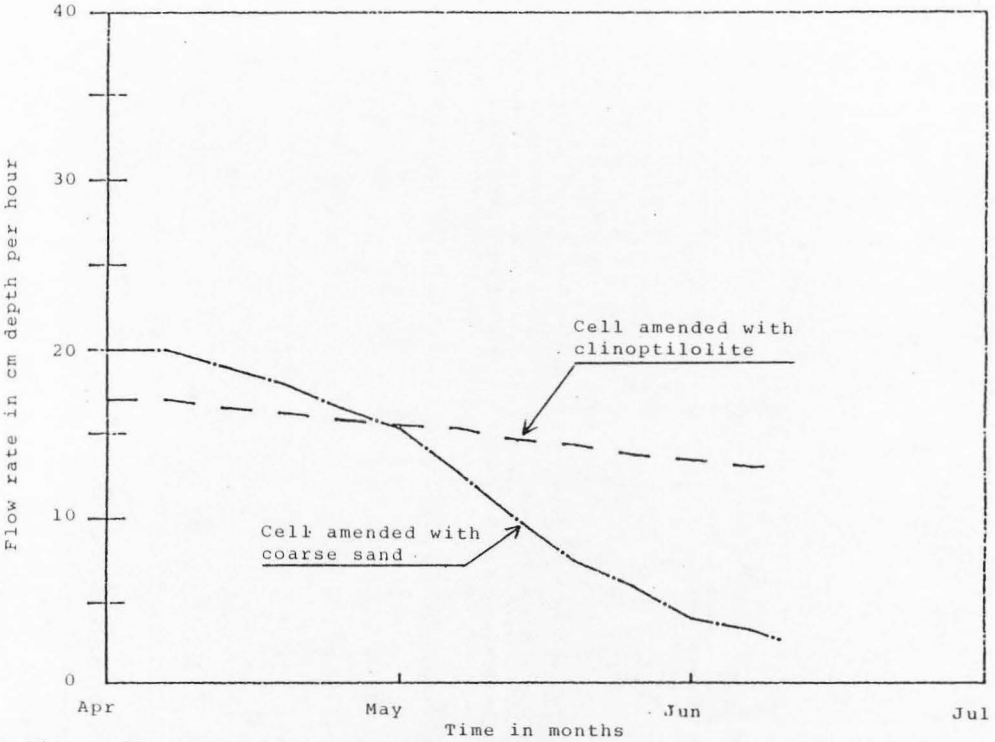


Figure 13. Filtration rates versus time for both cells of the pilot plant during spring runoff. Integrated area under the curves indicates total filtered volume.

restoring the SSF to service required that the sand under the GAC be scraped, since the major part of head loss development occurred under the GAC layer. Based on this observation, the same process might have returned the SSF amended with clinoptilolite to its original flow rate.

In conclusion, it appears that amending a filter with clinoptilolite resulted in an effluent approximately 30% lower in turbidity than the unamended cell. Since there is as much as a hundred fold reduction in particle counts when the turbidity is reduced from 1.0 to 0.1 ntu[46], maintaining a lower turbidity water results in greater safety with respect to removal of pathogenic organisms. The filter cycle was more than twice as long and the volume of filtered water was four times greater in the SSF cell amended with clinoptilolite. However, simply scraping the schmutzdecke from the surface of the clinoptilolite was insufficient to restore the filter to its original flow rate.

The nature of the schmutzdecke on the surface of the clinoptilolite was quite different from that on the sand (Figures 14 and 15). The schmutzdecke on the surface of the sand appeared to be incorporated into the surface of the sand, and it was not possible to separate the schmutzdecke from the sand. The sand and schmutzdecke together formed a crust which was somewhat rigid and could be broken up in chunks or clods. The schmutzdecke on the surface of the clinoptilolite, however, appeared

Figure 14. Closeup picture of the schmutzdecke on the surface of the clinoptilolite. Ballpoint pen is for scale.

Figure 15. Closeup picture of the schmutzdecke on the surface of the sand. Ballpoint pen is for scale.

to rest primarily on the top of the clinoptilolite, and adhered to it very little. It was possible to roll back a section of the schmutzdecke almost as though it were a carpet layer on top of the underlying clinoptilolite.

Metal Removal Through Columns

Analysis of the supernatant water indicated that the desired influent metal concentrations of 100 µg/l were not maintained consistently (Table 2). The variations in manganese concentrations did not exceed approximately 50%. However, the 12 day influent samples showed a three times higher lead concentration in column 3 than in column 1, and a two fold difference for arsenic. A possible explanation is that the lower level of lead in solution in column 1 is due to ion exchange taking place at the surface interface between the water and the clinoptilolite. Both columns were kept thoroughly stirred by air bubbling through the upper 80 cm of water. This stirring, combined with supernatant detention times of approximately 7 hours, may have allowed sufficient contact time with the clinoptilolite to remove a large fraction of the lead by ion exchange. It is also possible that the air bubbled through column 3 more rapidly than column 1, and that the resulting agitation held in suspension lead carbonate which would otherwise have settled out. Finally, it is possible that this variation is due to laboratory error, since both columns

Table 2. Influent and effluent manganese, lead, and arsenic concentrations in column 1 and column 3 (in micrograms/liter).

| Day of Experiment | Location of Sample | Column 1 | | | Column 3 | | |
|---|---|---|---|---|---|---|---|
| | | Mn | Pb | As | Mn | Pb | As |
| 1 | Influent | 92 | 70 | 76 | 88 | 45 | 86 |
| 12 | " | 118 | 25 | 44 | 139 | 74 | 83 |
| 1 | Effluent | <3 | 2 | 6.6 | 9 | <1 | 1.7 |
| 5 | " | <3 | 2.5 | 31 | <3 | <1 | 54 |
| 9 | " | 3 | <1 | 90 | <3 | <1 | 32 |
| 12 | " | <3 | <1 | 33 | <3 | <1 | 18 |
| 16 | " | 19 | 1.2 | 57 | <3 | 1.3 | 39 |
| 20 | " | 13 | <1 | 84 | <3 | <1 | 55 |
| 23 | " | 102 | <1 | 80 | <3 | <1 | 55 |
| 28 | " | 11 | 1.7 | 78 | <3 | <1 | 37 |

Column 1 consists of 20 cm of clinoptilolite on 100 cm of sand. Column 3 consists of 105 cm of sand on 15 cm of clinoptilolite.

were fed from the same stock solution, and neither the feed stock flow rates nor the filter flow rates ever differed by more than 10%, but this seems improbable, given the standards and controls which are run with each test. Since the arsenic was present as an anion ($HAsO$ ), it should not have been removed by ion exchange with clinoptilolite, which is a cation exchanger. Also, arsenic would not have formed precipitating salts with Ca or Mg at the concentrations at which these species were present[47].

Effluent metal concentrations indicate that lead was consistently removed to a level of less than 3 µg/l, which is below the federally mandated maximum of 50 µg/l[6]. Manganese levels in the effluent were less than 10 µg/l for the first two weeks for both columns, and remained less than 10 µg/l for column 3 to the end of the four week period. In column 1, however, the effluent manganese concentrations increased to approximately the level observed by Slezak[2], i.e., 10 to 20 µg/l, except for the sample collected on the 23rd day. It does not appear that this one high reading can be attributed to a breakthrough due to saturation of manganese in the filter, since the sample taken five days later contained only 11 µg/l of manganese. A breakthrough also appears unlikely based on the concentrations of manganese found on the sand and clinoptilolite in the columns, which had Mn concentrations 4 to 5 times higher at the surface of

either media than through the rest of the column, indicating that the columns were far from saturated with manganese.

Metal concentrations in the extraction samples from the media in the columns (Table 3) indicate that lead and manganese were almost entirely removed in the surface layers of the columns, regardless of whether the surface layer was sand or clinoptilolite. Arsenic deposition occurred through the entire depth of the columns, with the greatest concentration occurring at the surface. These results are virtually identical to those obtained by Slezak[2] using unseived construction sand and a sieved filter sand. This indicates that amending a SSF with a surface layer of clinoptilolite does not materially affect the removal of lead, manganese, and arsenic from the influent water, but that adding a layer of clinoptilolite underneath the sand may remove a slightly higher fraction of the manganese.

## Head Loss in Laboratory Columns

Head loss developed in the columns when they were first placed in operation in September, 1983, but visual inspection indicated that this was due to bubbles forming in the surface of the media rather than to schmutzdecke buildup. A sample of the gas comprising the bubbles was collected in early December and analyzed on a gas chromatograph. More than 99% of the sample consisted of

Table 3. Manganese, arsenic, and lead concentrations in 2 molar HCl extracts from samples of column filter medium. All concentrations are in micrograms per liter (ug/l).

| Sample Depth | Column 1 [Column configurations are shown on p.27 ] | Column 3 | Column 5 (Control) |
|---|---|---|---|
| Surface | Mn = 123,700 | Mn = 98,200 | Mn = 28,560 |
| | As = 400 | As = 366 | As = 22 |
| | Pb = 121,000 | Pb = 32,900 | Pb = 1,180 |
| 15 cm | Mn = 10,800 | Mn = 34,590 | Mn = 24,820 |
| 30 cm | Mn = 29,400 | Mn = 24,950 | Mn = 23,920 |
| | As = 105 | As = 257 | As = 132 |
| | Pb = 336 | Pb = 316 | Pb = 160 |
| 60 cm | Mn = 25,170 | Mn = 25,320 | Mn = 24,950 |
| 90 cm | Mn = 25,840 | Mn = 24,640 | Mn = 26,370 |
| 120 cm | Mn = 24,320 | Mn = 6,100 | Mn = 22,880 |
| | As = 121 | As = 260 | As = 85 |
| | Pb = 132 | Pb = 5,500 | Pb = 151 |

Metals from clino blank: Mn=5,600 As=145 Pb=5,400

Metals from sand blank: Mn=25,220 As= 55 Pb= 150

oxygen and nitrogen, in approximately atmospheric concentrations, indicating that it was simply air, and not a product of biological activity. The columns with coarse media on the surface allowed larger bubbles to form, and vibration in the column or column stand would cause them to escape and rise to the surface. This was apparently the reason that the columns with a surface layer of coarse media continued to function with only small head loss during this period.

At the same time that the gas sample was collected, water samples were also collected and analyzed for dissolved oxygen. The dissolved oxygen concentration in the influent was found to be 9.1 mg/l when the temperature was 18° C. Dissolved oxygen saturation at 18° C and at 760 mm mercury is 9.5 mg/l[13]. Atmospheric pressure in Logan is approximately 645 mm mercury, so dissolved oxygen saturation here should be (645/760)*9.5 = 8.06 mg/l. The effluent oxygen concentration was found to be 8.0 mg/l. Therefore, it appears that the water was entering the columns supersaturated with air which was coming out of solution in the surface layers of the media. The supersaturation was probably a result of the water being under approximately 25 feet of head and increasing in temperature by 3° to 15° C over the river temperature, depending on the time of year.

Beginning on 8 February 1984, compressed air was bubbled through the upper 80 cm of the supernatant in the

columns to bring gas concentrations to saturation. Beginning on 15 February, head loss readings for each pieziometer were taken 2 or 3 times weekly until 1 May, and once every 7 to 14 days thereafter. Head loss development with time at 15 cm depth in the columns is shown in Figure 16, and at 105 cm depth in Figure 17. The rapid fluctuations occurring in the first ten days of record in column 3 are a result of inaccurate adjustment of the compressed air, which resulted in a lack of air stripping for 1-2 days on two different occasions. The rapid increases in head loss were observed to be a result of bubble formation.

Head loss at 15 cm in columns 3, 4, and 5 dropped from 100+ cm on 8 February to a range of 12 to 21 cm on 15 February. This was the direct result of stripping the supersaturated air from the water, and thus preventing bubble formation in the surface layer of the media. Bubbles trapped at a greater depth returned to solution, and the head loss was reduced. The decrease in head loss over the first 8 days of readings at 105 cm in column 4 was due to the fact that the process of bubble dissolution was not complete when head loss readings were begun. After the first 8 days, head loss built up with time due to the deposition of influent suspended solids and the growth of biological mass. Head loss development was much more rapid for the columns with sand on the surface than for the columns which had a coarse medium on

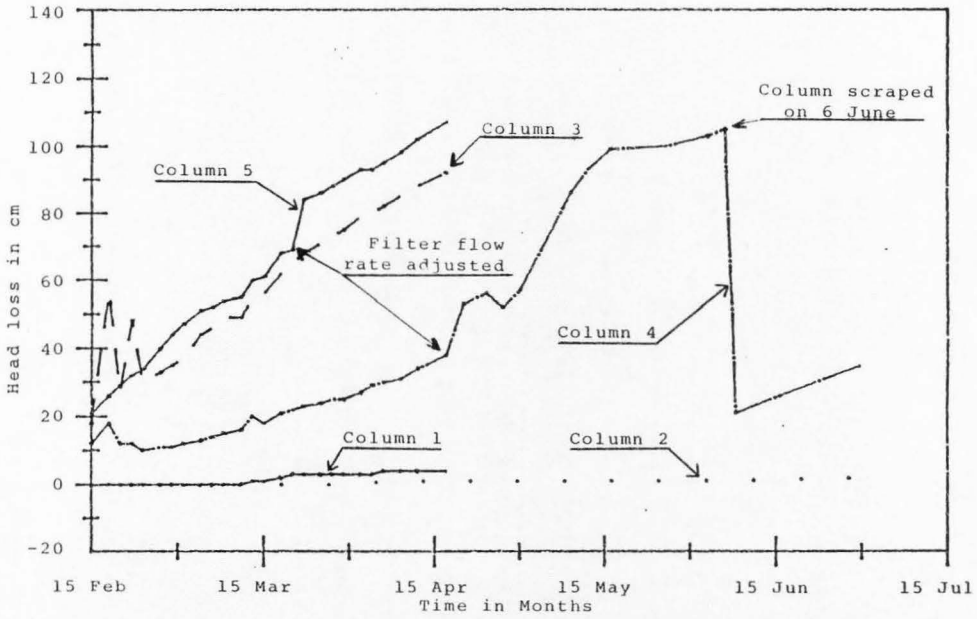


Figure 16. Head loss at a depth of 15 cm in the laboratory columns. Columns 1, 3, and 5 were taken out of service on 20 April for metal extraction of the media.

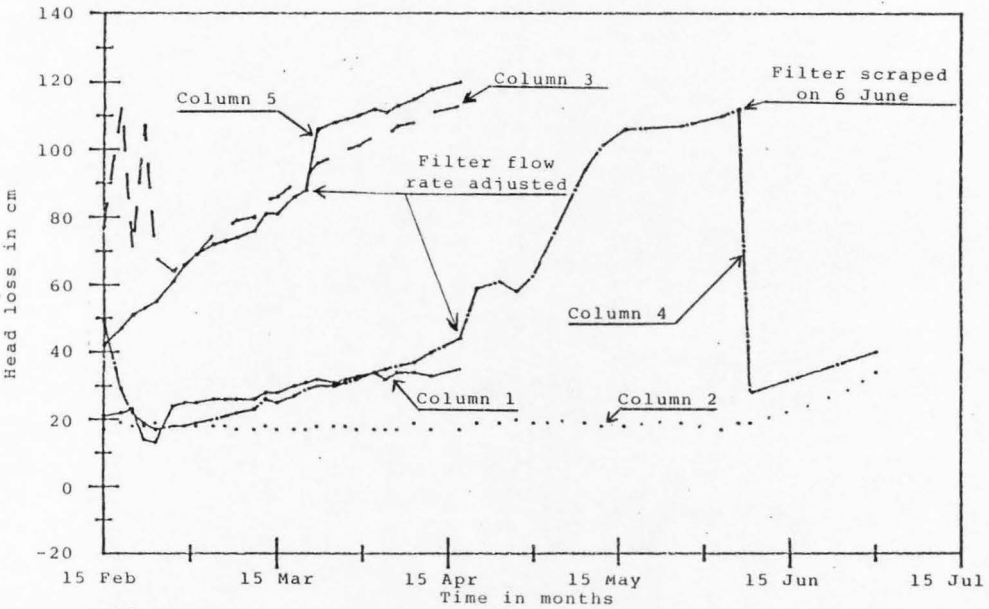


Figure 17. Head loss at a depth of 105 cm in the laboratory columns. Columns 1, 3, and 5 were taken out of service on 20 April for metal extraction of the media.

the surface. This is to be expected, since small pore spaces will be filled more easily than large ones, either by gas or by schmutzdecke.

An intermediate rate of head loss development occurred on column 4, which consisted of a homogeneous 3:1 mixture of sand and clinoptilolite. It is possible that this is due to increasing the average coarseness of the media, but this seems unlikely since the $D_{10}$ of the media would only be slightly increased, while the $D_{60}$ would be greatly increased, thereby increasing the magnitude of the uniformity coefficient. A larger uniformity coefficient is reported to result in poorer filter performance, since a large range in particle sizes results in less total pore space[1]. It is also possible that the slower development of head loss is a function of the presence of the clinoptilolite in the media.

The sudden decrease in head loss at 112 days occurred when column 4 was scraped on 6 June. This demonstrates that the design flow rate through the column is restored by scraping the schmutzdecke. Maintenance may be simpler on a homogeneous sand and clinoptilolite mixture than on a SSF amended with a surface layer of clinoptilolite since the entire layer of clinoptilolite may need to be removed and the underlying sand scraped to restore the flow rate.

Determination of Clinoptilolite
Cation Exchange Capacity (CEC)

The sodium concentration in the potassium chloride solution used to exchange sodium from the clinoptilolite was 2980 mg/l. The volume of solution was 500 ml, which results in a total weight of sodium in the solution of 1.49 grams. The atomic weight of sodium is 23, so this represents 1.49/23 or 0.0648 moles of sodium. Sodium carries a single positive charge, so one mole is equal to one equivalent. Therefore, 64.8 meq of sodium were exchanged from ion exchange sites on the 100 gram sample of clinoptilolite.

Biological Regeneration
of Clinoptilolite

The concentration of ammonium nitrogen in the supernatant of the batch reactor without nitrifiers added was 95 mg/l after 72 hours of stirring. The ammonium nitrogen concentration in the supernatant of the batch reactor with nitrifiers present was 135 mg/l. No explanation is offered as to why the concentration of ammonium was higher with than without nitrifiers, but it is evident that ample ammonium nitrogen remained in solution to satisfy the nitrifiers.

The amount of ammonium removed from all three samples of clinoptilolite was approximately equal. This indicates that very little or no ammonium was removed

from the clinoptilolite by nitrifying bacteria, and thus that biological regeneration did not take place.

Nitrate plus nitrite nitrogen concentrations in the supernatant of the reactor without nitrifiers remained relatively constant (Figure 18) at 0.22 to 0.26 mg/l throughout the entire test, except for the 48 hour sample, which showed 4.3 mg/l. Since samples both before and after the 48 hour one were quite consistent, it was concluded that it was an analytical error or the sample was contaminated. Nitrate plus nitrite nitrogen concentrations from the reactor with nitrifiers present are much higher (Figure 18). Results are reported throughout as nitrate plus nitrite, because problems were encountered with analysis of the samples. The automatic chemistry analyzer used to measure nitrate and nitrite concentrations determines the concentration of nitrate plus nitrite, and then the concentration of nitrite. Nitrate concentrations are then determined by subtracting nitrite from nitrate plus nitrite. For all samples taken after two hours, however, except the 72 hour sample, the nitrite concentration was higher than the nitrate plus nitrite concentration (Appendix C), which rendered nitrate nitrogen determinations impossible. At 72 hours, the nitrite nitrogen concentration was 18 mg/l, while the nitrate nitrogen was 7 mg/l. Nitrification occurs in two steps, with Nitrosomonas converting ammonium to nitrite, and Nitrobacter converting nitrite to nitrate[48].

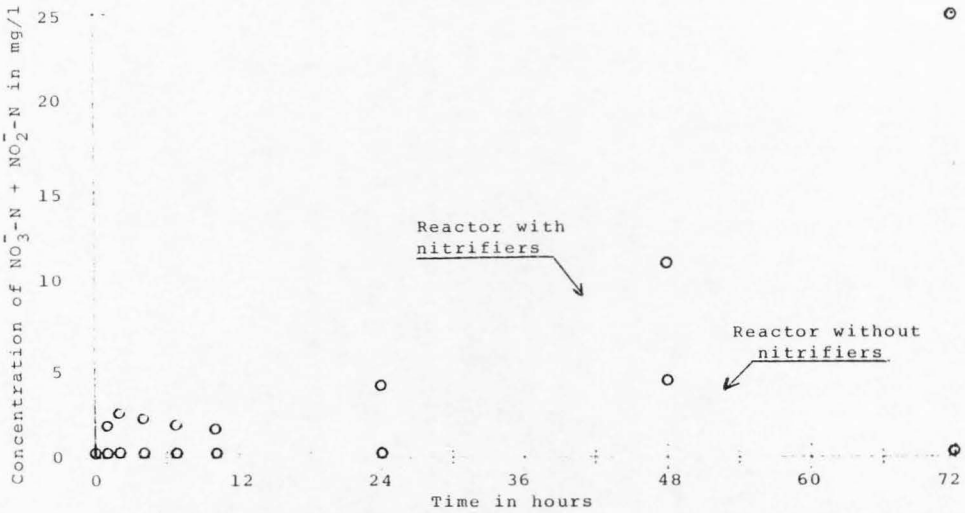


Figure 18. Concentrations of nitrate plus nitrite nitrogen vs. time in the supernatant of the batch reactor biological regeneration test.

Conversion of ammonium to nitrite is the rate limiting step that controls the overall reaction; therefore, nitrite levels do not usually build up to levels approaching those of ammonium or nitrate[48]. In this case, however, it appears that there were either very few Nitrobacter present, or that something was inhibiting their activity so as to prevent the conversion of nitrite to nitrate. Nitrate levels did appear to be increasing, since nitrate was separable from the nitrite plus nitrate concentration at 72 hours.

In any case, the nitrite and nitrate concentrations were insufficient to reduce the ammonium nitrogen concentrations to the point that biological regeneration of the clinoptilolite would take place.

## Reovirus Adsorption to Sand and Clinoptilolite

The results from the virus adsorption studies are shown in Table 4. In this study, reovirus type 1 was found to adsorb to sand and clinoptilolite with about equal efficiencies. At the end of the 42 hour batch reactor test, 76% ± 3% of the input reovirus was adsorbed to the clinoptilolite, and 81% ± 2% of the input reovirus was adsorbed to the sand. After the levels of adsorption were measured, viruses were eluted off the samples. The elution efficiency of reovirus from these solid media was quite low, 5% ± 4% for the sand, and 5% ± 1% for the

Table 4. Adsorption of reovirus to sand and clinoptilolite.

| Media | Virus particles/ml[a] | Distribution of Reovirus After 42 hours | | |
|---|---|---|---|---|
| | | % in water | % in coarse solids | % in fines |
| Clinoptilolite | $51 \times 10^7$ | 20 ± 4 | 1.6 ± 0.5 | 78 ± 9 |
| Clinoptilolite | $6.0 \times 10^7$ | 24 ± 3 | 1.3 ± 0.2 | 75 ± 8 |
| Clinoptilolite | $1.5 \times 10^7$ | 25 ± 3 | 1.4 ± 0.3 | 73 ± 9 |
| Clinoptilolite | $1.0 \times 10^7$ | 26 ± 2 | 1.4 ± 0.3 | 72 ± 8 |
| Sand | $51 \times 10^7$ | 17 ± 2 | 16 ± 2 | 67 ± 8 |
| Sand | $6.0 \times 10^7$ | 18 ± 1 | 18 ± 1 | 63 ± 7 |
| Sand | $1.5 \times 10^7$ | 20 ± 2 | 17 ± 1 | 63 ± 4 |
| Sand | $1.0 \times 10^7$ | 20 ± 2 | 16 ± 1 | 64 ± 9 |

a) Concentration of virus in Logan River Water at start of adsorption period.

clinoptilolite.

When the adsorbed reovirus was eluted from either sand or clinoptilolite, 25% ± 20% was still infectious. Thus, clinoptilolite appears to be quite similar to sand with respect to virus adsorption and inactivation.

Economics of Clinoptilolite
Versus Sand

Annual operation and maintenance costs of a SSF as determined by Slezak[2] are given in Table 5, and total annual cost, including fixed labor costs and a contingency factor of 1.1 are given in Table 6. The same assumptions regarding costs are used in this analysis, except where explicitly stated otherwise. Annual media cost, assuming that the scraped media is disposed, was calculated to be $6.40*A, where A is the area of filter in square meters[2]. Labor is calculated to be $4.20*A, on the same basis. These figures are based on a labor cost of $6.00 per hour, a sand cost of $32.00 per cubic meter, and assumes that each filter will be scraped to a depth of 2 cm, ten times annually. Total annual costs include supervisory labor at $15,000/year. A plant with a daily capacity of 0 to 1000 cubic meters was assumed to require half time supervision, one with 1000 to 2000 cubic meters full time supervision, and from 2000 to 4000 cubic meters 1.5 man-years of supervision per year. Also included in the total annual cost was a contingency factor of 10% of the base total annual cost (not including annualized construction costs).

Results obtained in this research project indicate that the use of clinoptilolite as a surface amendment to a SSF would require scrapings only twice a year.

Table 5. Summary of SSF operation and maintenance cost components[2].

| Category | Cost ($/yr) |
|---|---|
| Building energy | 5.38 A* |
| Process energy | 1.49 A |
| Chemicals | 0.66 A |
| Filter medium replacement | 6.40 A |
| Labor for scraping | 4.20 A |
| Total | 18.13 A |

*A = Filter area in square meters.

Table 5. Schedule of SSF operation and maintenance cost functions including supervisory labor and contingency factor [2].

| Plant Capacity (cubic meters/day) | Total Operating Cost Function ($/yr) |
|---|---|
| 0 - 1000 | 1.1 (18.13A* + 7500) |
| 1000 - 2000 | 1.1 (18.13A + 15000) |
| 2000 - 4000 | 1.1 (18.13A + 22500) |

*A = Filter area in square meters.

However, the labor required for a single scraping would be increased, probably by a factor of about four, since the sand surface under the clinoptilolite must be scraped, in addition to the schmutzdecke on top of the zeolite. A factor of four allows for scraping the schmutzdecke, moving the clinoptilolite, scraping the sand, and then replacing the clinoptilolite. Therefore, labor costs would be $3.36*A per year. Assuming that the clinoptilolite costs twice as much as the sand, and that 2 cm layers of both sand and clinoptilolite will be removed with each scraping, the annual material cost for the SSF amended with clinoptilolite will be $2.56*A. The assumption that the filter medium will be discarded after scraping was used to be consistent with the analysis performed by Slezak[2]. If the media cost as much as assumed, however, it would be more economical to wash and recycle them, thus the assumption of discarding the media is conservative.

It was assumed for the purpose of this study that a clinoptilolite amendment would make no difference in costs of building energy, process energy, chemicals, or supervisory labor. Actually, chemicals (chlorine) would be reduced somewhat, since less chlorine is required to produce a residual when the turbidity is lower. However, since the total chemical cost is only about 5% of the annual O&M cost, it was considered that savings would not materially affect overall economics of the SSF.

Construction and interest costs would also remain the same as for the unmodified SSF. Thus, the savings resulting from the use of clinoptilolite would amount to $4.68*A (Tables 5 and 7). A comparison of annual operation and maintenance costs for unmodified SSF (Table 6), SSF amended with a surface layer of clinoptilolite (Table 8), and package plant treatment is shown in Figure 19. The discontinuities in the lines representing SSF treatment, with and without clinoptilolite, is due to varying amounts of supervisory labor costs included.

Figure 20 indicates the relative construction costs for a SSF plant amended with clinoptilolite at flow rates of 0.1, 0.2, and 0.4 meter/hour, versus a package treatment plant. Finally, Figure 21 shows the relative total annualized costs for a SSF with a surface amendment of clinoptilolite at flow rates of 0.1, 0.2, and 0.4 meter/hour, and for package plants, as a function of treatment capacity. Unmodified SSF at 0.1 meter/hour is approximately 6.5% more expensive than the SSF amended with clinoptilolite at the same flow rate.

One assumption made by Slezak[2] which has a large bearing on the economic analysis is that the flow rate through the SSF would be 0.1 meter/hour. This is very conservative, since SSF systems typically operate at 0.1 to 0.4 meter/hour[1], and indicates that water treatment capacity can be increased by a factor of up to four without increasing plant size. Figures 20 and 21 show a

Table 7. Summary of operation and maintenance cost components for SSF amended with a surface layer of clinoptilolite.

| Category | Cost ($/yr) |
|---|---|
| Building energy | 5.38 A* |
| Process energy | 1.49 A |
| Chemicals | 0.66 A |
| Filter medium replacement | 2.56 A |
| Labor for scraping | 3.36 A |
| Total | 13.45 A |

*A = Filter area in square meters.

Table 8. Schedule of operation and maintenance cost functions including supervisory labor and contingency factor.

| Plant Capacity (cubic meters/day) | Total Operating Cost Function ($/yr) |
|---|---|
| 0 - 1000 | 1.1 (13.45A* + 7500) |
| 1000 - 2000 | 1.1 (13.45A + 15000) |
| 2000 - 4000 | 1.1 (13.45A + 22500) |

*A = Filter area in square meters.

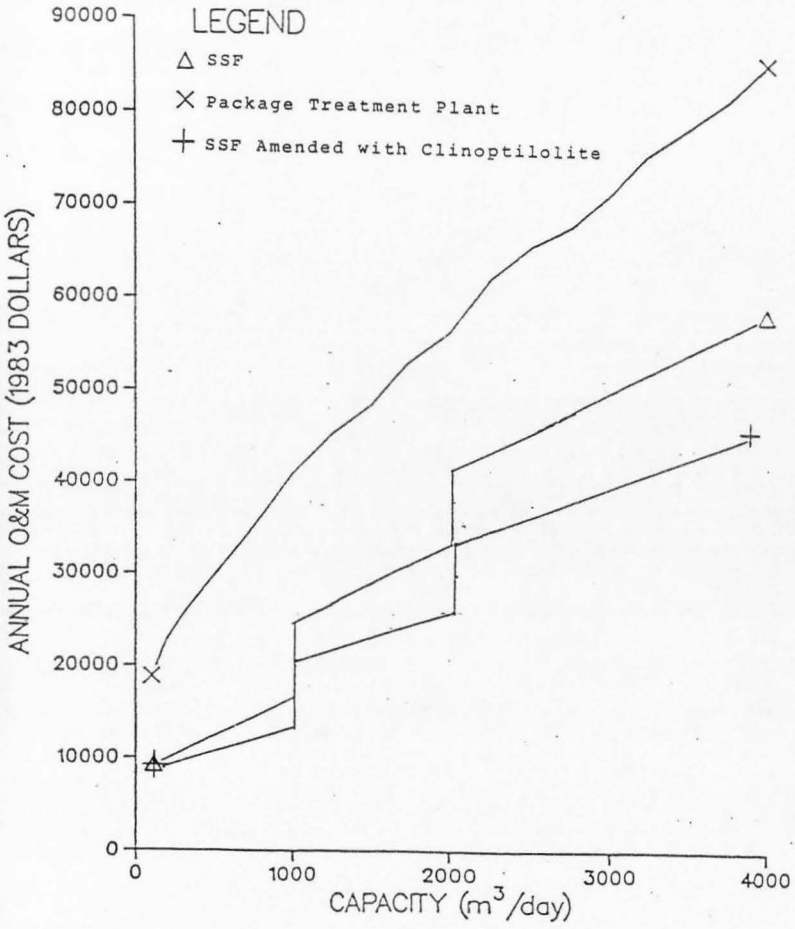


Figure 19. Comparison of annual operation and maintenance costs for SSF amended with clinoptilolite versus package treatment plants.

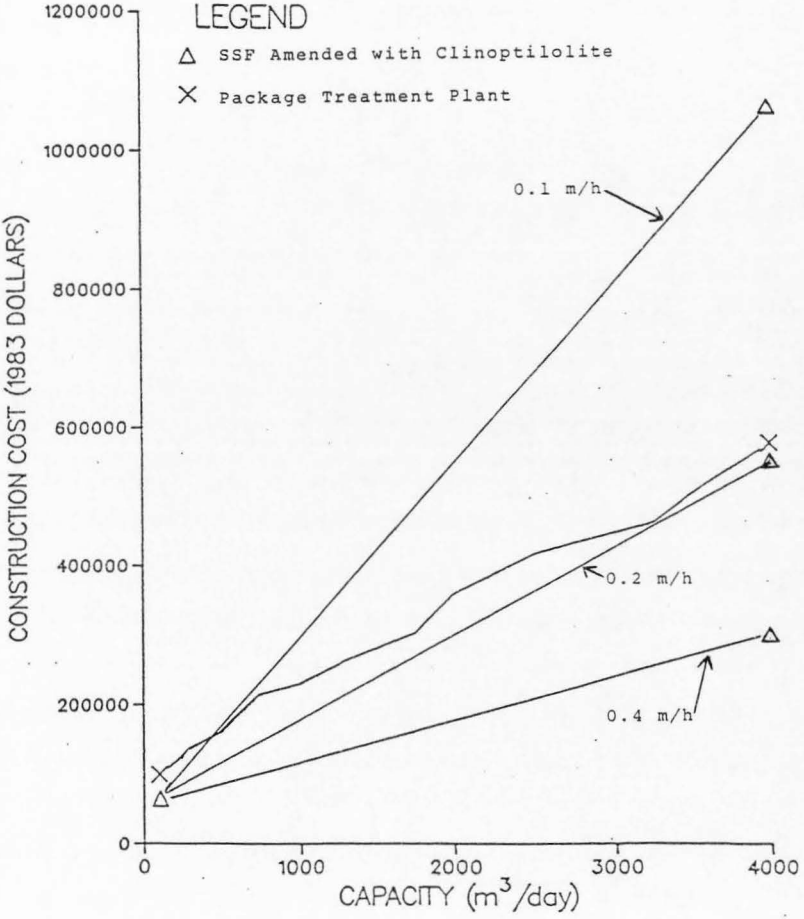


Figure 20. Comparison of construction costs for SSF amended with clinoptilolite and package treatment plants.

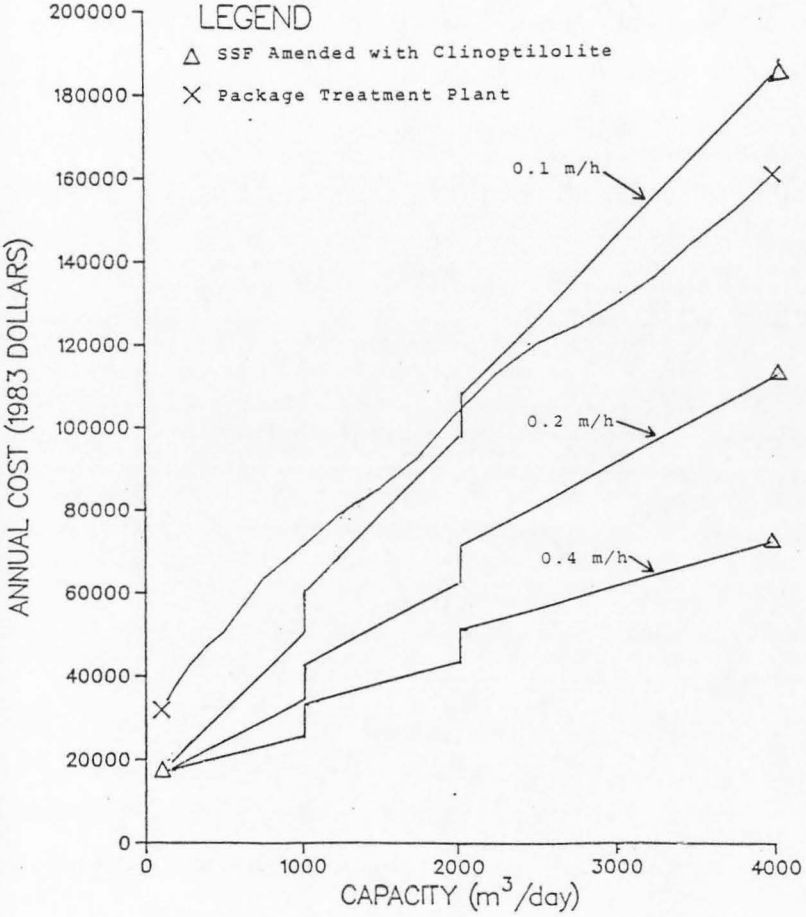


Figure 21. Comparison of annual costs of SSF amended with clinoptilolite and package treatment plants.

comparison of construction costs and total annualized treatment costs respectively, for a package treatment plant, and for SSF amended with clinoptilolite at flow rates of 0.1, 0.2, and 0.4 meter/hour.

The cell amended with clinoptilolite operated through the entire winter (October to April) without requiring scraping. This operation prevented freezing breakage which would have been beyond the budget of this project to repair. Damage from freezing occurs more readily when a cell is shut down. Therefore, if there were no economic advantage (due to reduced labor costs) with the use of clinoptilolite as an amendment to a SSF, the advantage of not having to shut down for scraping during sub-freezing temperatures could reduce contingency costs sufficiently to make clinoptilolite amended SSF desirable.

## Pilot Plant Design and O & M Improvements

Based on one year of operation of the UWRL pilot scale SSF facility, the greatest difficulty was found to be operation and maintenance related, i.e., freeze-up during the winter season. Many of these problems could be eliminated by adding the following criteria to the design used by Slezak[2]:

1) Provide heaters for the pump house and insulate it so that the interior temperature never falls below

5° C.

2) Place all exposed pipes, flow meters, valves, etc., inside the pump house or buried in insulated valve boxes. Do NOT leave any pipe exposed to outside air.

3) If floats are used to control the water elevation in the filter tanks, direct the influent flow so as to keep the floats free of ice.

4) Have heaters and covers available so that the filters may be scraped in any weather.

5) Filter tanks should be buried up to their freeboard elevation or otherwise insulated to protect from icing up inside.

6) Submersible pumps should be used so that there is no problem maintaining the prime on a pump.

7) It should also be noted that bacterial treatment efficiency decreased when the water temperature decreased from 10° to 3° C. Using Logan River water, this was not a serious problem, since bacterial concentrations decrease during the winter when runoff carries few organisms from the land to the river. Other water sources may have more elevated levels of bacterial contamination during the winter to ascertain that it meets drinking water standards.

# ENGINEERING SIGNIFICANCE

Although SSF systems have been in use for over 150 years, many of the parameters affecting their operation and effectiveness have not been thoroughly evaluated. One of these parameters is the effect of dual media operation with a natural ion exchange zeolite on the surface of the filter. It has been reported that a layer of granular activated carbon (GAC) on the surface of a SSF will greatly extend filter cycles[45]. An additional cost, however, is that the surface of the sand layer under the GAC must be scraped to restore flow rather than simply scraping the surface of the GAC. Therefore, filter scrapings are less frequent, but more difficult.

The purpose of the research component conducted with the field scale SSF facility was to determine if clinoptilolite, crushed to a consistency of 1 to 1.5 mm, and placed in a 20 cm layer on the surface of the SSF, would improve the performance and economics of the SSF water treatment process. Results obtained from October through March indicated that a surface amendment of clinoptilolite produces filter cycles four times longer with effluent as much as five times cleaner, bacteriologically.

Sand of approximately the same size as the clinoptilolite was placed in a 20 cm layer on the surface

of a second filter from April to June. The influent turbidity was approximately 20 ntu during this period, and filtration rates were again compared. Results indicated that filtration rates decreased more rapidly with a coarse sand surface amendment than with a surface amendment of clinoptilolite.

While clinoptilolite was not found to be superior to sand with respect to physicochemical virus adsorption characteristics, it did support a thicker schmutzdecke, which may result in superior biological virus removal from influent water. The bacterial quality of the effluents from the two filters was not significantly different in June, when the water temperature was 10° C, but in March, when the water temperature was 3° C, the effluent from the SSF amended with clinoptilolite contained more than five times fewer coliforms than the unamended sand cell.

In conclusion, a SSF amended with a surface layer of clinoptilolite produced an effluent water at least equal in quality to the effluent from an unmodified SSF for every parameter examined. Bacterial removal at 3° C and turbidity removal at all temperatures were superior. Economic analysis indicates also that a SSF amended with clinoptilolite is 10 to 25% less expensive to operate than an unamended SSF, depending on the flow rate.

# CONCLUSIONS

The following is a list of conclusions that can be drawn from this research.

1) Amending a cell of the pilot plant with a surface layer of clinoptilolite resulted in longer filter cycles and lower turbidity effluent.

2) Coliform removal exceeded 99.7% at all times in both cells of the pilot plant. SSF treatment efficiency at 3° C is less effective than at 10° C, with respect to coliform removal.

3) The pilot plant cell amended with clinoptilolite produced an effluent approximately 30% less turbid than the unamended cell when influent turbidities ranged from <1 ntu to >20 ntu. Neither cell, however, ever exceeded 1 ntu of turbidity in the effluent.

4) Amending the control cell of the pilot plant with a surface layer of coarse sand did not result in decreased rate of head loss development comparable to that on the cell amended with a layer of clinoptilolite.

5) Winter operation of an uncovered SSF in Logan (northern Utah climate) is feasible if certain design and maintenance factors are observed.

6) If water is supersaturated with air, the air must be desorbed before reaching the filter, or head loss development will be rapid due to bubble formation in the surface of the filter.

7) Head loss development in the columns was most rapid when the surface layer consisted of unsieved sand, and least rapid when the surface layer consisted of sieved sand or clinoptilolite.

8) Removal of lead, manganese, and arsenic does not differ greatly between a SSF with no amendment, and a SSF amended with a layer of clinoptilolite.

9) Schmutzdecke development varied greatly between the glass columns (indoors) and the pilot plant (outdoors). This was possibly due to differences in lighting.

10) Radiolabeled reovirus in water adsorb with approximately equal efficiency (76 vs. 81%) to sand and to clinoptilolite and elution efficiency is quite low (~5%).

11) Active reovirus eluted from the clinoptilolite or sand was approximately 1% of the reovirus originally adsorbed to either media.

12) Biological regeneration of ammonium saturated clinoptilolite did not occur to a useful degree during a 72 hour exposure to 800 ml of filtered Logan River water and 100 ml of activated sludge.

# RECOMMENDATIONS FOR FURTHER RESEARCH

1. Head loss data for the column consisting of a 3:1 ratio of sand to clinoptilolite indicate much longer filter cycles than for the pure sand. Research into this configuration should be continued.

2. Core samples of mature schmutzdecke on both sand and clinoptilolite should be compared to columns of clean sand and clinoptilolite with respect to viral removal and inactivation at normal SSF filtration rates. All samples should be only 10 to 20 cm deep to determine full schmutzdecke effect. These core samples from the pilot plant should be collected before the surface of the schmutzdecke is exposed to the air to assure that the organisms present are not affected.

3. Coliform removal should be tested monthly, or as frequently as is necessary to determine removal rates over a range of temperatures in both cells of the pilot plant.

4. Coliform removal should also be tested at different flow rates to determine treatment efficiency over a range of flow rates.

5. A layer of clinoptilolite should be placed on a base of coarse sand or pea gravel to determine if this results in longer filter cycles, since the sand beneath the clinoptilolite appears to be where serious head loss develops. Water quality should also be monitored to see if it is equal to that from the SSF amended with clinoptilolite.

# REFERENCES


1. Huisman, L. and Wood, W. E. Slow Sand Filtration. World Health Organization, Geneva, Switzerland (1974).

2. Slezak, L. A. Evaluation of Slow Rate Sand Filtration for Providing Drinking Water for Small Communities. Master's Thesis. Utah State University, Logan, Utah (1983).

3. Sherman, J. D. Ion exchange separation with molecular sieve zeolites. In Sherman, J. D. (ed.), Adsorption and Ion Exchange Separation. AICHE Symposium Ser. No. 179:98-116 (1978).

4. McConnell, L. K., and Sims, R. C. The Effect of Sand Size on Removal of Reovirus and Escherichia Coli by Slow Rate Sand Filtration. Proceedings of the American Water Works Association Annual Meeting, Las Vegas, Nevada (1983).

5. McConnell, L. K. Evaluation of the Slow Rate Sand Filtration Process for Treatment of Drinking Water Containing Viruses and Bacteria. Master's Thesis. Utah State University, Logan, Utah (1984).

6. United States Environmental Protection Agency (USEPA). Quality Criteria for Water. USEPA, Washington, D. C. (July 1976).

7. Poynter, S. F. B. and Slade, J. S. The Removal of Viruses by Slow Sand Filtration. Progress in Water Technology, 9:75 (1977).

8. Culp, G. L. and Culp, R. L. New Concepts in Water Purification. Van Nostrand Reinhold Co., New York, New York (1977).

9. Snoeyink, V. L. and Jenkins, D. Water Chemistry. John Wiley and Sons, New York, New York (1980).

10. Sanks, R. L. Water Treatment Plant Design. Ann Arbor Science, Ann Arbor, Michigan (1980).

11. Wheaton, R. M. and Seamster, A. H. A Basic Reference on Ion Exchange. From the Encyclopedia of Chemical Technology, Volume 11. John Wiley and Sons, Inc., New York, New York (2nd ed. 1966).

12. Semmens, M. J. and Martin, W. Studies on Heavy Metal Removal from Saline Waters by Clinoptilolite. AICHE Symposium Ser. No. 197:76:367-376 (1980).

13. Sawyer, C. N. and McCarty, P. L. Chemistry for Environmental Engineering. McGraw-Hill Book Company, New York, New York (1978).

14. Klein, L. River Pollution, Vol. II. Causes and Effects. Butterworth and Co., London (1962).

15. White, G. C. Handbook of Chlorination. Van Nostrand Reinhold Company, New York, New York (1972).

16. Johnson, J. D. Disinfection Water and Wastewater. Ann Arbor Science, Ann Arbor, Michigan (1975).

17. Sims, R. C. and Hindin, E. Use of Clinoptilolite for Removal of Trace Levels of Ammonia in Reuse Water. In Chemistry of Wastewater Technology. Ann Arbor Science, Ann Arbor, Michigan (1978).

18. Mercer, B. W., Ames, L. L., Touhill, C. J., Van Slyke, W. J., and Dean, R. B. Ammonia Removal from Secondary Effluents by Selective Ion Exchange. Paper presented at the Water Pollution Control Federation Conference, Dallas, Texas (1969).

19. Stanier, R. Y., Doudoroff, M., and Adelberg, E. A. The Microbial World. Prentice-Hall, Inc., Englewood Cliffs, New Jersey (2nd ed. 1963).

20. Bailey, J. E. and Ollis, D. F. Biochemical Engineering Fundamentals. McGraw-Hill Book Co., New York, New York (1977).

21. Semmens, M. J. and Goodrich, R. R., Jr. Biological Regeneration of Ammonium Saturated Clinoptilolite. Environmental Science and Technology, 11:3:255-259 (March 1977).

22. Tisdale, S. L. and Nelson, W. L. Soil Fertility and Fertilizers. Macmillan Publishing Co., New York, New York (1975).

23. Brady, N. C. The Nature and Properties of Soils. Macmillan Publishing Co., New York, New York (8th ed. 1974).

24. Allen, H. E. and Kramer, J. R. Nutrients in Natural Waters. John Wiley and Sons, New York, New York (1972).

25. Bitton, G. Adsorption of Viruses onto Surfaces in Soil and Water. Water Research, 9:473-482 (1975).

26. Bitton, G., Masterson, N., and Gifford, G. E. Effect of a Secondary Effluent on the Movement of Viruses Through a Cypress Dome Soil. Journal of Environmental Quality, 5:4:370-381 (April 1976).

27. Tanimoto, R. M. Migration of Bacteriophage T4 in Percolating Water Through Selected Oahu Soils. Technical Report No. 20, for Pollution Effects on Groundwater Recharge in Hawaii. OWRR Project No. A-001-HI, (1968).

28. Drewery, W. A., and Eliassen, R. E. Virus Movement in Groundwater. Journal Water Pollution Control Federation, 40:R257-R266 (1968).

29. Gerba, C. P., and Lance, J. C. Poliovirus Removal from Primary and Secondary Sewage Effluent by Soil Filtration. Applied and Environmental Microbiology, 36:2:247-254 (Feb. 1978).

30. Robeck, G. G., Clark, N. A., and Dostal, K. A. Effectiveness of Water Treatment Processes in Virus Removal. Journal of the American Water Works Association, 54:10:1275-1292 (Oct. 1962).

31. Jenkins, S. P. The Effectiveness of Sand Filters for the Removal of Specific Viruses from Water Using Selected Cations as Filter Aids. Alabama Water Resources Research Institute Bulletin No. 35 (1978).

32. Fox, K. R. Miltner, E. J., Logsdon, G. S., Dicks, D. L., and Drolet, L. F. Pilot Plant Exploration of Slow Rate Sand Filtration. Paper presented at Innovative Filtration Seminar, National Conference of the American Water Works Association, Las Vegas, Nevada (1983).

33. Cleasby, J. L. Slow Sand Filtration and Direct In-line Filtration of a Surface Water. Paper presented at Innovative Filtration Seminar, National Conference of the American Water Works Association, Las Vegas, Nevada (1983).

34. Lloyd, B. The Construction of a Sand Profile Sampler: Its Use in the Study of the Vorticella Populations and the General Interstitial Microfauna of Slow Sand Filters. Water Research, 7:963-973 (1973).

35. Slade, J. S. Enteroviruses in Slow Sand Filtered Water. Journal of the Institute of Water Engineering and Science, 32:530 (1978).

36. Standard Methods for the Examination of Water and Wastewater. APHA, AWWA, and WPCF. Washington, D. C. (15th ed. 1980).

37. Neter J., Wasserman, W., and Whitmore, G. A. Applied Statistics. Allyn and Bacon, Inc., Boston, Massachussetts. (2nd ed. 1982).

38. Keeney, D. R. and Nelson, D. W. Nitrogen-Inorganic Forms. In Page, A. L., ed., Methods of Soil Analysis, Part II: Chemical and Microbiological Properties. American Society of Agronomy, Madison, Wisconsin (2nd ed. 1982).

39. Hunter, W. M. and Greenwood, F. C. Preparation of Iodine-131 Labelled Human Growth Hormone of High Specific Activity. Nature, 194(4827):495-496 (1962).

40. Smith, R. E., Zweerink, H. J., and Joklik, W. K. Polypeptide Components of Virions, Top Component and Cores of Reovirus Type 3. Virology, 39:791-810 (1969).

41. Smith, E. M. and Gerba, C. P. Development of a Method for Detection of Human Rotavirus in Water and Sewage. Applied and Environmental Microbiology, 43:1440-1450 (June 1982).

42. Odum, E. P. Fundamentals of Ecology. W. B. Saunders Co., Philadelphia, Pennsylvania (3rd ed. 1971).

43. Metcalf & Eddy, Inc. Wastewater Engineering: Treatment, Disposal, Reuse. Revised by Tchobanoglous, G. McGraw-Hill Book Co., Boston, Massachussetts (2nd ed. 1979).

44. Hulbert, Matthew L. Personal communication (1984).

45. Reid, P. W. Water and Wastewater Treatment Technologies for Developing Countries. Ann Arbor Press, Ann Arbor, Michigan (1982).

46. Tate, C. H. and Trussell, R. R. The Use of Particle Counting in Developing Plant Design Criteria. Journal of the American Water Works Association, 70:691-698 (1978).

47. Weast, R. C. Handbook of Chemistry and Physics. CRC Press, Inc., Boca Raton, Florida (64th ed. 1983).

48. Clark, J. W., Viessman, W., and Hammer, M. J. Water Supply and Pollution Control. Harper and Row, Publishers, New York, New York (3rd ed. 1977).

# APPENDICES

## Appendix A

### Head Loss Development in Columns (Measured in cm)

| Date | #1 Scraped Sept. 1983 | | | | #2 Scraped 10 Feb. 1984 | | | | #3 Scraped Jan. 1984 | | | | #4 Scraped Sept. 1983 | | | | #5 Scraped Sept. 1983 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Depth (cm) | | | | Depth (cm) | | | | Depth (cm) | | | | Depth (cm) | | | | Depth (cm) | | | |
| | 15 | 45 | 75 | 105 | 15 | 45 | 75 | 105 | 15 | 45 | 75 | 105 | 15 | 45 | 75 | 105 | 15 | 45 | 75 | 105 |
| 15 Feb | 0 | 10 | 17 | 21 | 0 | 3 | 14 | 17 | 18 | 59 | 69 | 77 | 12 | 39 | 47 | 49 | 21 | | 34 | 42 |
| 18 Feb | 0 | 13 | 19 | 22 | 0 | 6 | 14 | 19 | 57[a] | 103 | 108 | 113 | 18 | 22 | 26 | 29 | 26 | | 39 | 47 |
| 20 Feb | 0 | 13 | 19 | 23 | 0 | 6 | 14 | 18 | 27 | 54 | 61 | 70 | 12 | 16 | 19 | 22 | 29 | | 43 | 51 |
| 22 Feb | 0 | 8 | 12 | 14 | 0 | 6 | 14 | 18 | 48[a] | 90 | 101 | 107 | 12 | 15 | 17 | 19 | 32 | | 45 | 53 |
| 24 Feb | 0 | 7 | 10 | 13 | 0 | 6 | 14 | 19 | 30 | 51 | 58 | 68 | 10 | 13 | 15 | 17 | 34 | | 48 | 55 |
| 27 Feb | 0 | 14 | 20 | 24 | 0 | 6 | 14 | 18 | 33 | 48 | 55 | 64 | 11 | 14 | 16 | 18 | 40 | | 53 | 61 |
| 29 Feb | 0 | 14 | 21 | 25 | 0 | 6 | 14 | 18 | 35 | 50 | 57 | 67 | 11 | 14 | 16 | 18 | 44 | | 58 | 66 |
| 2 Mar | 0 | 15 | 21 | 25 | 0 | 6 | 14 | 18 | 37 | 52 | 59 | 69 | 12 | 15 | 18 | 19 | 47 | | 61 | 69 |
| 5 Mar | 0 | 15 | 22 | 26 | 0 | 6 | 14 | 18 | 44 | 59 | 66 | 75 | 13 | 16 | 18 | 20 | 51 | | 65 | 72 |
| 7 Mar | 0 | 15 | 22 | 26 | 0 | 6 | 14 | 18 | 46 | 61 | 68 | 77 | 14 | 17 | 19 | 21 | 52 | | 66 | 73 |
| 9 Mar | 0 | 16 | 22 | 26 | 0 | 6 | 13 | 17 | 49 | 63 | 70 | 79 | 15 | 18 | 20 | 22 | 54 | | 67 | 74 |
| 12 Mar | 0 | 15 | 22 | 26 | 0 | 6 | 13 | 17 | 49 | 64 | 71 | 80 | 16 | 19 | 21 | 23 | 55 | | 68 | 76 |
| 14 Mar | 1 | 17 | 24 | 28 | 0 | 6 | 14 | 18 | 55 | 70 | 76 | 85 | 20 | 23 | 25 | 26 | 60 | | 74 | 81 |
| 16 Mar | 1 | 16 | 24 | 28 | 0 | 6 | 13 | 17 | 56 | 71 | 77 | 86 | 18 | 21 | 23 | 25 | 61 | | 74 | 81 |
| 19 Mar | 2 | 18 | 25 | 30 | 0 | 6 | 14 | 17 | 62 | 76 | 83 | 90 | 21 | 23 | 25 | 27 | 68 | | 80 | 86 |
| 21 Mar | 3 | 20 | 27 | 31 | 0 | 6 | 13 | 17 | 65 | 78 | 85 | 92 | 22 | 25 | 27 | 29 | 69 | | 81 | 88 |
| 23 Mar | 3 | 20 | 27 | 32 | 0 | 6 | 14 | 18 | 68 | 82 | 88 | 96 | 23 | 26 | 28 | 30 | 89[b] | | 98 | 106 |
| 26 Mar | 3 | 20 | 27 | 31 | 0 | 6 | 14 | 18 | 71 | 84 | 90 | 98 | 24 | 26 | 28 | 30 | 86 | | 100 | 108 |
| 28 Mar | 3 | 20 | 27 | 32 | 0 | 6 | 14 | 18 | 73 | 86 | 92 | 100 | 25 | 27 | 29 | 31 | 88 | | 102 | 109 |
| 30 Mar | 3 | 20 | 28 | 33 | 0 | 6 | 14 | 17 | 75 | 87 | 93 | 101 | 25 | 28 | 30 | 32 | 90 | | 103 | 110 |
| 2 Apr | 3 | 22 | 29 | 34 | 0 | 6 | 14 | 17 | 79 | 91 | 96 | 104 | 27 | 30 | 32 | 34 | 93 | | 106 | 112 |
| 4 Apr | 3 | 21 | 28 | 32 | .5 | 6 | 14 | 17 | 80 | 91 | 97 | 104 | 29 | 31 | 33 | 35 | 93 | | 105 | 111 |
| 6 Apr | 4 | 22 | 29 | 34 | 1 | 6 | 14 | 17 | 82 | 94 | 100 | 107 | 30 | 32 | 34 | 36 | 95 | | 107 | 113 |
| 9 Apr | 4 | 22 | 29 | 34 | 1 | 7 | 15 | 19 | 85 | 96 | 101 | 108 | 31 | 34 | 36 | 37 | 98 | | 109 | 115 |

Broken piezometer tube

[a] Stopped bubbling for 1 day.

[b] Adjusted flow rate from 23 to 30.

Column 1: 20 cm of clinoptilolite on top of 100 cm sand.
Column 2: 20 cm of coarse sand on top of 100 cm sand.
Column 3: 100 cm of sand on top of 15 cm of clinoptilolite.
Column 4: Homogeneous mixture of 25% clinoptilolite and 75% sand by volume.
Column 5: Pure sand control column.

Appendix B

Daily Air Temperatures,
October to April

| Date | High | Low | Date | High | Low |
|---|---|---|---|---|---|
| 1 Oct | 16 | 12 | 18 Nov | 2 | -6 |
| 2 | 14 | 9 | 19 | -1 | -4 |
| 3 | 17 | 7 | 20 | 0 | -6 |
| 4 | 23 | 7 | 21 | -4 | -12 |
| 5 | 26 | 12 | 22 | -4 | -11 |
| 6 | 26 | 12 | 23 | -1 | -6 |
| 7 | 26 | 14 | 24 | -1 | -4 |
| 8 | 26 | 14 | 25 | -2 | -6 |
| 9 | 24 | 14 | 26 | -1 | -10 |
| 10 | 16 | 10 | 27 | -1 | -6 |
| 11 | 16 | 7 | 28 | -2 | -8 |
| 12 | 11 | 5 | 29 | -2 | -2 |
| 13 | 12 | 2 | 30 | 3 | -1 |
| 14 | 2 | 1 | 1 Dec | 5 | -5 |
| 15 | 8 | -2 | 2 | 2 | -3 |
| 16 | 10 | -2 | 3 | 2 | -3 |
| 17 | 12 | 1 | 4 | -2 | -12 |
| 18 | 11 | 0 | 5 | -5 | -10 |
| 19 | 10 | 0 | 6 | -4 | -16 |
| 20 | 12 | 0 | 7 | -6 | -10 |
| 21 | 12 | 0 | 8 | 1 | -4 |
| 22 | 15 | 0 | 9 | 0 | -4 |
| 23 | 10 | 3 | 10 | 5 | -1 |
| 24 | 8 | -2 | 11 | 2 | -3 |
| 25 | 12 | -2 | 12 | -2 | -8 |
| 26 | 12 | -4 | 13 | -2 | -6 |
| 27 | 13 | -2 | 14 | -1 | -5 |
| 28 | 12 | 0 | 15 | 0 | -12 |
| 29 | 14 | 2 | 16 | -1 | -9 |
| 30 | 8 | 2 | 17 | 1 | -13 |
| 31 | 8 | 1 | 18 | -6 | -9 |
| 1 Nov | 10 | 2 | 19 | -2 | -14 |
| 2 | 10 | 3 | 20 | -7 | -19 |
| 3 | 15 | 4 | 21 | -12 | -22 |
| 4 | 15 | 4 | 22 | -14 | -29 |
| 5 | 11 | 4 | 23 | -17 | -21 |
| 6 | 13 | 0 | 24 | -13 | -20 |
| 7 | 12 | -4 | 25 | -4 | -13 |
| 8 | 0 | -9 | 26 | 0 | -8 |
| 9 | 1 | -4 | 27 | -1 | -6 |
| 10 | 6 | 1 | 28 | -10 | -17 |
| 11 | 6 | -3 | 29 | -10 | -22 |
| 12 | 7 | -4 | 30 | -3 | -12 |

| | | |
|---|---|---|
| 13 | 6 | -4 |
| 14 | 2 | -6 |
| 15 | 3 | -6 |
| 16 | 5 | 1 |
| 17 | 4 | -3 |
| 5 Jan | -2 | -7 |
| 6 | -3 | -8 |
| 7 | -5 | -10 |
| 8 | -5 | -9 |
| 9 | -2 | -12 |
| 10 | -6 | -10 |
| 11 | -2 | -9 |
| 12 | -3 | -11 |
| 13 | -3 | -10 |
| 14 | -8 | -14 |
| 15 | -5 | -18 |
| 16 | -10 | -18 |
| 17 | -12 | -29 |
| 18 | -18 | -28 |
| 19 | -14 | -28 |
| 20 | -17 | -27 |
| 21 | -12 | -15 |
| 22 | -6 | -10 |
| 23 | -4 | -8 |
| 24 | -1 | -4 |
| 25 | 2 | -8 |
| 26 | 2 | -11 |
| 27 | -2 | -12 |
| 28 | 0 | -18 |
| 29 | -5 | -20 |
| 30 | -6 | -22 |
| 31 | -8 | -19 |
| 1 Feb | -6 | -20 |
| 2 | -7 | -20 |
| 3 | -6 | -20 |
| 4 | -5 | -20 |
| 5 | -5 | -20 |
| 6 | -6 | -14 |
| 7 | -1 | -12 |
| 8 | -3 | -15 |
| 9 | -5 | -13 |
| 10 | 0 | -8 |
| 11 | 1 | -11 |
| 12 | 2 | -5 |
| 13 | 2 | -3 |
| 14 | -1 | -11 |
| 15 | -1 | -8 |
| 16 | -1 | -6 |
| 17 | 0 | -8 |
| 18 | 1 | -12 |
| 19 | -3 | -15 |
| 20 | -4 | -18 |
| 31 | 0 | -8 |
| 1 Jan | -2 | -6 |
| 2 | -2 | -8 |
| 3 | -6 | -9 |
| 4 | -1 | -6 |
| 25 Feb | 1 | -8 |
| 26 | 2 | -14 |
| 27 | -4 | -19 |
| 28 | -2 | -18 |
| 29 | -2 | -13 |
| 1 Mar | 2 | -10 |
| 2 | 2 | -6 |
| 3 | 2 | -12 |
| 4 | -1 | -15 |
| 5 | -2 | -10 |
| 6 | -1 | -6 |
| 7 | 2 | -10 |
| 8 | 0 | -7 |
| 9 | 2 | -7 |
| 10 | 1 | -8 |
| 11 | 3 | -10 |
| 12 | 5 | -6 |
| 13 | 3 | -11 |
| 14 | 4 | -5 |
| 15 | 2 | -7 |
| 16 | 3 | -6 |
| 17 | 5 | -4 |
| 18 | 7 | -7 |
| 19 | 4 | -3 |
| 20 | 3 | -4 |
| 21 | 4 | -4 |
| 22 | 4 | -7 |
| 23 | 3 | -4 |
| 24 | 2 | -8 |
| 25 | 4 | -4 |
| 26 | 3 | -6 |
| 27 | 2 | -7 |
| 28 | 2 | -4 |
| 29 | 2 | -1 |
| 30 | 4 | -3 |
| 31 | 6 | -2 |
| 1 Apr | 5 | -2 |
| 2 | 4 | -4 |
| 3 | 7 | -4 |
| 4 | 10 | 2 |
| 5 | 14 | 4 |
| 6 | 12 | -4 |
| 7 | 6 | -2 |
| 8 | 12 | -3 |
| 9 | 3 | -3 |
| 10 | 5 | -4 |
| 11 | 6 | -6 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 21 | | -7 | -15 | 12 | Apr | 7 | -4 |
| 22 | | 0 | -16 | 13 | | 9 | -2 |
| 23 | | -1 | -14 | 14 | | 13 | 4 |
| 24 | | 0 | -9 | 15 | | 18 | 5 |
| 16 | Apr | 20 | 6 | | | | |
| 17 | | 22 | 3 | | | | |
| 18 | | 16 | 2 | | | | |
| 19 | | 2 | -2 | | | | |
| 20 | | 2 | -1 | | | | |
| 21 | | 10 | 0 | | | | |
| 22 | | 12 | 2 | | | | |
| 23 | | 11 | -2 | | | | |
| 24 | | 14 | -5 | | | | |
| 25 | | 4 | -5 | | | | |
| 26 | | 2 | -6 | | | | |

Appendix C

Batch Reactor Nitrate Data

Table of nitrate and nitrite nitrogen concentrations found in the supernatant of the batch reactor biological regeneration tests (values in mg/l).

| Time in hours | Reactor without nitrifiers | | Reactor with nitrifiers | |
|---|---|---|---|---|
| | NO3+NO2 | NO2 | NO3+NO2 | NO2 |
| 0 | 0.21 | <0.002 | 0.42 | 0.30 |
| 1 | 0.23 | 0.003 | 1.80 | 0.92 |
| 2 | 0.24 | 0.004 | 2.50 | 1.60 |
| 4 | 0.25 | 0.072 | 1.55 | 2.20 |
| 7 | 0.25 | 0.033 | 1.17 | 1.80 |
| 10 | 0.23 | 0.029 | 1.03 | 1.60 |
| 24 | 0.26 | 0.033 | 2.80 | 4.10 |
| 48 | 4.30 | 0.036 | 10.1 | 11.0 |
| 72 | 0.20 | 0.006 | 25.0 | 18.0 |

Appendix D

Statistical Analysis

A statistical analysis was conducted to determine the probability of a coliform bacteria passing through the cell amended with clinoptilolite or the unamended cell using the binomial probability equation.

$$P(x) = \binom{n}{x} p^x (1-p)^{n-x}$$

where

$$\binom{n}{x} = \frac{n!}{x!(n-x)!}$$

If it is assumed that the probability of a coliform passing either cell is equal, i.e., p=0.5 and (1-p)=0.5, then the probability of 51 coliforms passing the unamended cell vs. 9 coliforms passing the cell amended with clinoptilolite is 1.2 x 10E-8 or 99.9999988% assurance it is not by chance.

Other values for p and (1-p) will be tested to determine values for p and (1-p) which will provide 95% assurance that the values for p and (1-p) must not be any closer to 0.5.

| assumed value of p | assumed value of (1-p) | probability that 51:9 ratio would occur |
|---|---|---|
| 0.2 | 0.8 | 0.08642 |
| 0.3 | 0.7 | 0.00366 |
| 0.25 | 0.75 | 0.02395 |
| 0.22 | 0.78 | 0.05603 |
| 0.23 | 0.77 | 0.04329 |
| 0.225 | 0.775 | 0.04941 |

The value 0.04941 is close enough to 0.05 or 5% that it can be stated with 95% assurance that the ratio of (1-p) to p cannot be less than 0.775/0.225 or 3.44 to 1. Thus we can be 95% sure that a coliform bacteria is at least 3.44 times more likely to be found in the effluent from the unamended cell of the pilot plant than from the cell amended with clinoptilolite.